MAN'S CONTROL OF HIS ENVIRONMENT

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A Survey of Science

A three-year program in junior-high-school science, embodying the recommendations of the Thirty-first Yearbook. See the preface, pages iii–iv.

III. MAN'S CONTROL OF HIS ENVIRONMENT

Please notice these nine important features:

1. *Its underlying theme:* the extent to which man has learned to control the forces in his environment that cause change. See the preface, page iv.

2. *Its organization into large units of work*, each of which develops some important scientific concept and sets up problem situations which, because of their genuine interest and importance, really challenge the pupil. See the preface, pages iii–vi, and the contents, pages vii–xii. The units are arranged in such an order as to give the learner an increasingly enlarged understanding of the major theme of the book.

3. *Its pupil foreword*, which not only explains at the outset the major theme and underlying point of view of the book, but also motivates the pupil's approach. See pages xiii–xiv.

4. *Its unit previews*, which awaken keen interests and establish desirable points of view. See pages 4, 102, 196.

5. *Its smoothly developed chapters*, each of which gives the pupil a picture of some situation that is rich in potentialities for further study. Glance through any chapter.

6. *Its chapter summaries*, which state simply and concisely the salient principles and facts which the pupil has just studied. See pages 28, 51, 72.

7. *Its wealth of questions and things to do*, which stimulate thought and bring pupils into actual contact with scientific phenomena. See pages 97, 98, 99, 154, 155.

8. *Its useful glossary of science words*. See page 1, at end of book.

9. *Its abundant illustrations*, which help the pupil materially to visualize what he is studying and assist him in arriving at desired understandings.

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Herbert Paus

Man exercises a Measure of Control over his Environment

A · SURVEY · OF · SCIENCE · III
FOR JUNIOR HIGH SCHOOLS

Man's Control of his Environment

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A · SURVEY · OF · SCIENCE
FOR JUNIOR HIGH SCHOOLS

I. The World Around Us

II. This Changing World

III. Man's Control of his Environment

The Athenæum Press
GINN AND COMPANY · PRO-
PRIETORS · BOSTON · U.S.A.

Preface

This series has been prepared for use in the junior-high-school grades. The authors have been guided in this work by the recommendations set forth in the report "A Program for Teaching Science," in the Thirty-first Yearbook of the National Society for the Study of Education (1932), Part I. In this report it is recommended that:

> The science courses of the seventh, eighth, and ninth grades should be considered as an integral part of the program of science instruction for the period of elementary and secondary education. The science of this level should, on the one hand, be built upon and comprehend the science of the first six grades; it should, on the other hand, serve as a basis for an orientation into the special sciences of the high school for those who are to continue beyond the ninth grade. Above all else, it must provide the most worthwhile science experiences possible for the pupils on this level, and it must be in accord with the acceptable objectives of a liberal education for boys and girls of ages twelve to sixteen years.

In this report of the National Society for the Study of Education there is a list of principles and generalizations which, taken collectively, define the major contributions of science to human welfare and to human interests. This list, with some modifications, has been used for guidance in the selection of instructional material for these books.

The series constitutes A Survey of Science. It is an exploratory survey of the areas of scientific achievements defined by the important principles and generalizations. The series is designed to give to children an acquaintance with, and an ability to use, the products of scientific achievements that are interesting and important in the unspecialized intellectual activities of educated laymen.

The point of view developed in this report of the National Society for the Study of Education and accepted in the preparation of this series is that the aim of instruction in science is threefold:

1. To develop an understanding of, together with an ability and desire to use, those scientific attainments that may function in intellectual experiences most common to everybody.
2. To develop some understanding of, together with an ability and desire to use, some of the methods by means of which scientific attainments have been achieved.
3. To engender the scientific attitude of respect for truth and for scientific methods.

The attainment of this aim will function in the lives of maturing youths and in their lives as adults, as a stimulation to wholesome intellectual endeavors and as a source of personal satisfaction due to enriched appreciation.

For the attainment of this aim these books furnish a wealth of vicarious experiences and suggestions for actual contacts with challenging scientific phenomena. At the end of each chapter there are many carefully prepared aids to learning, which take the form of direct experiences. These direct and vicarious experiences supplement one another in developing for the learner an enlargement of understanding of important principles and generalizations, and serve to develop an ability to use scientific methods of work.

The one theme that runs through these books is "Living things — including man — are dependent upon one another and upon the physical environment." The course develops an understanding of the ways in which this dependence functions. In the first book of the series (*The World Around Us*) emphasis is placed upon getting acquainted with the environment. The second book (*This Changing World*) recognizes as a major theme the changes that are going on in living and nonliving things. *Man's Control of his Environment* is the third book of this series.

Like the two preceding volumes, this book is organized into relatively few teaching units. These are divided into conveniently arranged chapters. Each unit develops understanding of some large feature in the environment, over which man is exerting some measure of control. The subject matter of a unit has been brought together because it

belongs together for the development of an understanding of the means whereby this control has been attained.

The major achievements resulting from work in science may be grouped as follows:

1. Through understanding of living things and their relations to the physical environment, man is able to produce a food supply that is in excess of his needs. Only a generation ago there seemed to be well-supported fears for the security of the food supply. These fears have now been dispelled.
2. Through understanding of the nature of matter, materials for work in construction have been made available in abundance and in great variety
3. Through understanding of energy, forces with their origins in coal and running water are made available to do the work of the world. There is, it seems, an abundance of energy under control for every conceivable need. This energy flowing through the wheels of machinery may be used to do the drudgery that has been done by men and beasts of burden.
4. Through understanding of organisms, including himself, man is able to control in large measure the causes of illness and to maintain for himself a higher degree of bodily vigor. Diseases very destructive to human life only a short while ago are now so definitely under control that cases of illness from them are extremely rare.
5. Through understanding of the physical and biological environment, intellectual experiences of a recreational nature are made possible. We like to know, we seize opportunities to see things, and we derive satisfactions from our observations as we are able to interpret them.
6. Through understanding of the physical and biological factors of the environment, man is able more adequately to understand himself and the character of his responses.

Achievements in science, including scientific methods and attitudes, have contributed enormously to human satisfaction. We like to think straight. Mental disturbances arise when we are blocked in ability to do so. Through understanding we gain in ability to think through our problems, including those most intimate ones relating to our own personal adjustments. Fears that have attended the thinking of people at an earlier time are dispelled by ability

to understand. Furthermore, understanding fosters attitudes favoring the search for understandings, and these attitudes function as determiners of behavior. Thus the individual progresses in attaining freedom from unfounded prejudices and superstitions. Understanding of cause and effect in some relations fosters the search for cause and effect in other relations. Modern psychology abundantly supports the conclusion that ability to use understandings is the effective foundation for building those mental attitudes which are the bases of desirable behaviors.

Growth in ability to understand *The World Around Us*, *This Changing World*, and *Man's Control of his Environment* must result in growth in ability to understand man's great achievements and to take part in them. Through such understandings and activities, attitudes favoring desirable achievements must be engendered. We learn to do by doing, and our behavior is influenced by the character of our achievements. Richness in behavior is a product of richness in experiences. In A Survey of Science the authors have provided rich experiences in great variety.

The authors have received assistance from many sources. They acknowledge especially their indebtedness to Mr. Arthur V. Linden of Teachers College, Columbia University. The authors wish also to express appreciation for suggestions made by Professor Kirtley F. Mather of Harvard University, who has read the book in proof. Others who have read all or parts of the proof and contributed useful suggestions include Mr. Herbert J. Arnold of New College; Mr. O. E. Underhill of the State Teachers College at New Britain, Connecticut; Mr. J. F. Montgomery of the Public Schools, New Rochelle, New York; Mr. N. E. Bingham of the Lincoln School, New York City; and Miss June M. Common of the Horace Mann School, New York City. Acknowledgment is made to Charles E. Merrill Company for permission to adapt material quoted in Chapter XXXIII from a manuscript in the social studies being prepared for publication by Herbert B. Bruner and C. Mabel Smith.

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Unit II · How has Man's Changing Civilization disturbed the Balance of Nature?

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To the Readers of this Book

If someone were to say to you that you might have four wishes, for what should you ask? You may find it hard to answer this question. But if you were to review the struggles of the human race, you would see clearly what the desires of men have been. It is human desires that have been responsible for the achievements of man. Obviously man works for what he wants.

In a sense the wants of man are simple. His four major desires are (1) for food, clothing, and shelter; (2) for health and bodily vigor; (3) for leisure time with opportunity to direct his own activities; and (4) for ability to understand himself and the things round about him. Achievement of these desires has not come merely by wishing. It has come as a result of continuous effort.

As a result of long, hard effort man has increased enormously his power to produce the materials for food, clothing, and shelter. Similarly he has brought under control many of the conditions which in the past have been major causes of ill health. Energy from natural resources, that is, from coal and falling water, has replaced in large measure the muscular energy of man. Thus man has been freed from hard labor and, to a greater extent than ever before, has time for leisure pursuits. Through this leisure there has come to the individual an opportunity to gain understanding of himself and of the environment of which he is a part.

The achievements in control of the environment have come, in large part, through the applications of the methods of scientific study. Since these methods are relatively new in the history of the race, the great achievements in control have come fairly recently. In fact, the achievements have come so fast during the past century that it has been difficult to make needed adjustments. The story of changes in the activities of man is in a sense a story of progress toward gaining his main desires. In order that you may take your place in society it is important that you study these achievements.

In this book, *Man's Control of his Environment*, there is an account of some of man's important accomplishments. You may see how he has learned to control the growth of plants and animals and to use this control in the production of an abundant food supply; how he has learned to control energy from natural resources and to use this energy, in place of muscular energy, to do the work of the world; and how he has enlarged, through painstaking effort, his ability to understand himself and to interpret the phenomena of nature.

Man's Control of his Environment is the third of a series of three books. The title of the series is A Survey of Science. The first book is called *The World Around Us*. In it you will find a simple story of how plants and animals, including people, live in their physical environment. The second book, *This Changing World*, tells about changes in the environment. This third book of the series tells how man has learned to control, to some extent, the forces that cause change. Through the use of his intellect he has learned to use forces, like those that wear down mountains, to run machinery. He has learned to control some of the forces that affect the character of the soil, and he has used this knowledge to produce more wheat, corn, and cotton.

The wealth of the world is in the forces and in the materials that we may use. Through the study of science man has learned the vastness of the wealth on earth. There is more energy than we can use, more food than we can eat, and metals for every need.

In a world of abundance what are the limits placed on man's achievements? Through the use of his intellect he has built up the complex civilization of today. We may adapt ourselves to it through fuller understanding of ourselves and of the factors that produced the conditions in which we live. A Survey of Science shows something of the progress man has made in understanding the world around him, in understanding himself, and in gaining control of his environment. These accomplishments, which have come so rapidly, seem to suggest that far greater things lie ahead. Never before was there a time that offered so many interesting and important things to do.

THE AUTHORS

A SURVEY OF SCIENCE

BOOK THREE

The Indians helped the Early American Pioneers to cultivate Native Plants

UNIT I

How has Man gained Increasing Control over the Living Things in his Environment?

Chapter I · Where, When, and Why have Plants been Cultivated?

Chapter II · How have we developed New Plants and New Varieties of Plants?

Chapter III · How and Why have we domesticated Animals?

Chapter IV · What Conditions give the Most Efficient Growth of Crops?

AT THE BEGINNING of our national history we could truly say that we were an agricultural nation. Even as late as 1880 there were 72 per cent of our people living on farms, but with the twentieth century came great changes. In 1929 less than 25 per cent of our population lived on farms. The nation had become primarily an industrial one rather than an agricultural one. This change, however, made the place of the farmer even more important. People in cities depend upon agriculture for life. Imagine one of our great cities cut off for even one week from the sources of its food supplies. Such a city would face starvation.

But what, you say, has this to do with science? Picture the change which has taken place in agriculture. First and foremost, the application of scientific principles to farming has made it possible for the farmer to secure a much greater yield per acre for almost every crop. Many other scientific achievements have aided the farmer. New types of agricultural products have been developed. Old crops, such as fruits and fresh vegetables, can be obtained by larger portions of the country because of new methods of shipping and preserving food. Through irrigation, areas once arid and dry now produce large crops. Better varieties of grain have been developed, as in the case of wheat, and scientific methods of cattle-breeding have made possible the raising of new types. The farmer's methods of work were once almost primitive. Today complex machinery has replaced simple machinery on the farm, just as it has in the factory.

So you see that science has played a big part in the agricultural life of America. Not all of this story can be told, nor can all of its meaning be pointed out. Perhaps, however, as you read this unit, you will see some of this development and will be able to understand more completely the problems of the farmer of today.

Chapter I · Where, When, and Why have Plants been Cultivated?

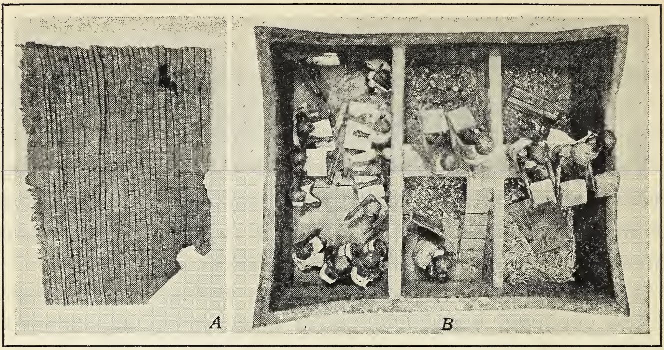
Each of us has at some time been aware of how certain weather conditions tend to create food shortages. Droughts, for instance, make vegetables scarce or tough. They may cause cattle to die for lack of green plants and water.

And yet most of us, in America as well as in other parts of the civilized world today, in spite of all our worries, have enough to eat and to spare, with variety sufficient to provide well-balanced meals.

Mankind, however, has not always been so fortunate. Man has many times known hunger and starvation when crops failed; and even when he had a surplus of food to store he had not always satisfactory means of storing it. Nor could he transport it from regions of plenty to regions of famine, for heated trains and artificial refrigeration are recent inventions. Besides, there have been whole races of men who had no crops to fail, who depended upon whatever food they could pick up as they moved about. These people must have known only too often what it felt like to be hungry. Food for them was often really scarce.

In the neighborhood of a million years ago, or a little more, primitive man first wandered through the forests and over the plains of Europe, finding shelter usually in rock caves along the banks of streams. He hunted animals. He got shellfish from lakes and seas. He ate seeds, leaves, roots, and berries. He may even have stored some of them against the needs of winter.

At a later date man domesticated certain wild animals — cattle, sheep, goats, and horses. Probably about this time certain observing individuals discovered how to sow seeds and raise crops. It was a discovery of no small importance. Think a minute of the consequences.



Metropolitan Museum of Art

Fig. 1. Agriculture is More Ancient than History

In *A* is shown some pleated cloth made by ancient Egyptians, and in *B* some grain (with models of servants preparing it) found in the graves of ancient Egypt

Plants have been raised for food

Previously man had been obliged to hunt for his food and to live in a region where it was plentiful. Now he could raise it. He had to sow the seeds and tend the growing crop, but when autumn came he had food aplenty. Because of his discovery a longer stay in one place became possible. More permanent homes could be built.

Thus man settled down. Thus he became a farmer rather than, or in addition to being, a hunter and a herdsman. He had still to learn how to keep his land fertile, how better to plow and harrow it. He had still to discover the great variety of valuable crops. He had still to improve his crops by selection and crossbreeding. But the first step in the conquest of plants had been taken.

Agriculture is more ancient than history. Among the relics of the Swiss lake-dwellers, who lived more than ten thousand years ago, have been found wheat grains, barley, millet, flax, and peas. Wheat and linen cloth have been taken from the tombs of Egyptian mummies (Fig. 1). Even these date back two to four thousand years, perhaps more.

A. For What Purposes has Man wanted Plants?

Probably there has never been a time when man did not use plants for food. But how about other uses?

Recall the old Indian herb doctors or the less civilized medicine man. Recall the supposedly learned Greek physicians. Their remedies were chiefly from the plant world. Indeed, man seems to have used plants for his medicine almost as many years as for his food. But do we find plants and their products still worth using for medicine today?

Ewing Galloway

FIG. 2. A Modern Pharmacist depends to a Great Extent upon Drugs obtained from Plant Substances

The answer is that doctors today would be at a loss without them. Take a few instances. Quinine, the remedy for malaria, comes from the bark of the cinchona tree in the mountains of Ecuador. Chaulmoogra oil, used as a cure for the dreaded disease leprosy, comes from a tree in India. Digitalis, belladonna, gentian, eucalyptus, peppermint, fennel, sarsaparilla, juniper, and caraway are among the plants valued for use in medicine. If you should look over the bottles behind a modern prescription counter, such as the one in Fig. 2, you would find a very large percentage containing drugs obtained from plant substances.

Plants are used for medicine

Or suppose we consider man's clothing. Possibly the first man to decorate or protect himself with a covering used the hide of an animal. But the day must soon have arrived when he began to use grasses, leaves, and the bark of trees. Fossil flax seeds have been found in Europe among the relics of the Stone Age. The development of the art of weaving is prehistoric. Cotton cloth and linen cloth are more ancient than the first written records.

Plants are used for clothing

Plants, more especially trees and grasses, have long served for shelter. Suppose you should try to trace the development of housing through the ages and then discard all the houses where plants and their products were absolutely essential. What would remain? The most ancient caves, which were stone, and the most modern skyscrapers, which are stone and metal.

Plants serve as shelter

And last, but perhaps not least, an important use of plants is for the beautifying of our towns and our homes. Who is not attracted to gay blossoms? Perhaps you have a flower bed similar to that shown in Fig. 3. Who does not love the beauty of trees? In this respect early man was probably no different from the man of today.

Plants add beauty to the world

B. What were Some of the First Crops Raised?

As we have already suggested, some of our most important plants have been cultivated for so many centuries that it is hard to trace their ancestry or to determine the time when they were wild.

Wheat without doubt had its origin in Asia, probably in the region near Palestine. This, as you know, is a land in which lived a highly civilized people in the earliest days of history. Wheat spread to other parts of Asia, and to Europe and Africa. In the cooler or drier parts of the earth man developed new

The use of wheat is very old

FIG. 3. Cultivated Plants serve Man's Sense of Beauty as well as his Material Needs

Do you think a garden such as this is evidence of man's control over nature?

varieties of wheat that could resist cold or drought. In Fig. 4 are shown two types of wheat: one the wild variety which still grows near Palestine today; the other one of our best-yielding modern varieties. But of this development you will read more in a later chapter.

Wheat has formed the "staff of life" for the white race of the Old World since the earlier part of the Old Stone Age. It came into America for the first time soon after the landing of Columbus.

Barley, oats, rye, rice, and millet have also been used for thousands of years. These grains are used less widely than wheat, but are nevertheless important as food both for man and for his domestic animals.

Indian corn, or maize, is strictly American. It was unknown in the Old World until taken there by the English and the Spaniards returning from their explorations on these continents. It is unknown now in a wild state, although there is a wild grass called teosinte in Central America which is very closely related to it. Maize was

grown by American Indians over wide geographic areas. Although originally doubtless a semitropical plant, like teosinte today, it grew in the dry sandy uplands as far north as New York State and the Great Lakes region as well as in the hot, damp lowlands in Central America and in the hot, dry plateaus of Peru. How, you may ask, could a single plant be adapted to so many environments? For each different environment the Indians had developed or selected a different variety of maize. To what extent the Indians consciously developed these differences we do not of course know. It is probable that some new kinds resulted naturally. It is further likely that the most intelligent among the Indian farmers were quick to take advantage of nature, and saved each year the best of these new varieties. In any case, there was plenty of time for advances to be made in the hundreds of years maize was cultivated upon this continent before the arrival of the Europeans. Today, cultivated corn is far different from the early types, as you can see from Fig. 5.

Maize is a New World plant, the "staff of life" of the Indians

Fig. 4. Man has improved Wheat through a Knowledge of the Laws which control its Growth

Is there any question in your mind as to which is the modern and which the ancient wheat?

Corn crops cover more ground at present than any other cultivated crop in America — about 100,000,000 acres.

Three fourths of the corn goes to pigs, cattle, horses, and poultry, both as cornstalks and as seed. It is used in our own diet as corn meal and in the form of corn oil, corn sirup, and cornstarch. The value of the annual corn crop of about three billion bushels is normally in the neighborhood of two billion dollars.

Cotton was a prehistoric crop in both the Old World and the New World

Cotton was grown in India centuries before the Christian Era. Reports of it came to Europe through Herodotus, a Greek writer of history. Later, soldiers of Alexander the Great brought back seeds and planted them. Arabs brought it into Spain in the Middle Ages. Cotton was valued highly in Europe at that time, but chiefly as a curiosity! It was used little in competition with the linen fibers from the flax plant.

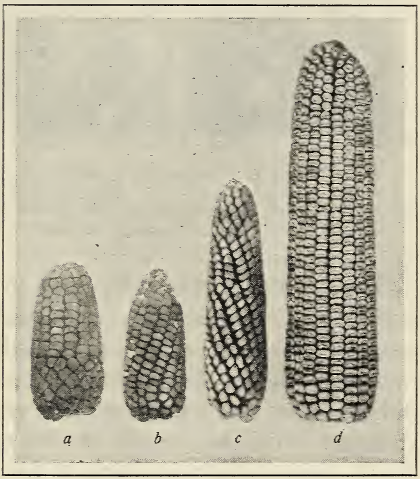


Fig. 5. The Cultivated Corn of Today is Far Different from the Early Types

a, b, c, corn from Peruvian graves[1]; *d,* modern corn

Then Columbus discovered America; and here in Central America and upon the islands of the West Indies he found natives dressed in garments beautifully woven from cotton! The fact that he recognized the cotton was one of the chief reasons why he thought he had reached India, for he and his crew had heard about the cotton that grew in India. And soon the Spaniards were demanding ransoms from the Aztecs, Mayas, and Incas, often in the form of cotton cloth.

[1] The photographs of early types of corn are by R. P. Orchard.

FIG. 6. Cotton is a Tropical or Subtropical Plant

The cotton plant is shown in *A*. Plantations such as that shown in *B* cover large areas of the southern United States

The cotton plants cultivated in India and in Central and South America were very much alike. And in both centers, though so widely separated, the processes of making the cloth were for all practical purposes identical! How did the same plant happen to be cultivated on both hemispheres? Did the people of one country carry it to the other, along with knowledge of the art of weaving? Scientists and students of history wish they knew, but no one does.

Cotton is a tropical or subtropical plant, requiring a moist sandy soil and a temperature of at least 60° F. through the growing season. It is grown today in nearly all parts of the tropics where there is sufficient moisture.

A cotton plant is very different in appearance from the group of grasses to which wheat, corn, rice, barley, sugar cane, sorghum, and other grains belong. The cotton plant is a mallow, related to rose mallow and hollyhocks. The cotton, as shown in Fig. 6, grows on a small bush. Its

flowers present an appearance not unlike yellow, pink, and white roses. The cotton fibers are attached to the seeds, serving as a protection for them. The seeds are separated from the cotton fibers by machinery. The fibers are made into a thread or cloth. The oil from the seeds is used to make oleomargarine or other food substances, and what is left is fed to animals of the farm.

Sugar cane also comes from ancient India

Sugar cane too was grown in ancient India. Neither the ancient Romans, Greeks, Egyptians, nor Babylonians had any sugars except honey and fruit juices. Sugar cane was introduced into Europe by the Arabs during the Middle Ages. Used first as a medicine, it later came into more common use as a luxury for the rich. With the opening of the New World it was brought into the West Indies, where it proved especially well adapted to the new soil and climate. And because it was well adapted to these islands, it was raised there in larger and larger quantities. Soon rich and poor alike could have sugar. Between 1821 and 1921 the yearly amount of sugar used per person in the United States increased from eight pounds to eighty pounds.

Sugars are pure carbohydrates. They therefore contain only the chemical elements carbon, hydrogen, and oxygen. There are several different sugars. That most abundant in sugar cane and sugar beets is known as sucrose, $C_{12}H_{22}O_{11}$. Honey and fruit juices contain a sugar called glucose, which has the formula $C_6H_{12}O_6$. Sucrose is obtained commercially from sugar cane, from sugar beets, and from the sugar maple. Glucose is made from starch. The familiar corn sirup is chiefly glucose made from cornstarch.

Sugar cane is a tall-growing perennial native to the tropics. It is a member of the grass family. It belongs to the same plant group as the bamboo, which it greatly resembles in appearance. The cane plant has a round jointed stalk, 1 to $2\frac{1}{2}$ inches thick, which grows to a height of from 6 to 24 feet. At the joints are lines called nodes,

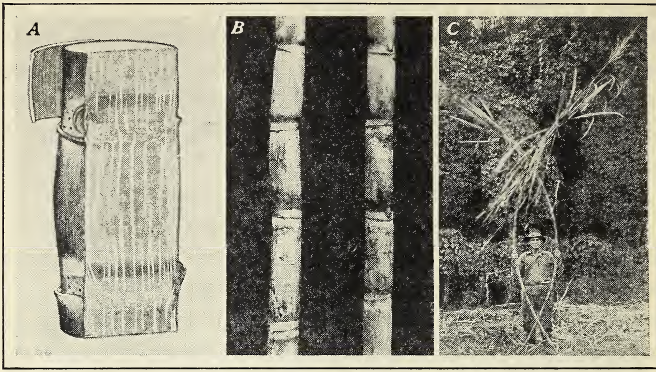


Fig. 7. Sugar Cane is a Tall-growing Perennial Native to the Tropics

A, the inside of the sugar cane, is a mass of fibrovascular bundles. The cane juice is extracted by crushing it. *B*, on each node of the sugar-cane plant is a bud, or sucker, which when planted produces a new plant. Following the text, can you find a node and an internode? *C*, stalks of cane. On a sugar-cane plantation at the time of the maturity of the plants, one sees acres of them stretching as far as the eye can see

and the piece of cane between two joints is called the internode. On each node there is a bud, inclosed in a small sheath. They are the suckers which when planted produce new canes.

As the plant grows, it sends out long narrow leaves from opposite sides of the nodes in a graceful sweeping effect. These leaves are from 1 to $2\frac{1}{2}$ inches wide, from $1\frac{1}{2}$ to 4 feet long, and are arranged in two rows spaced alternately in the same manner that spikes are set in telegraph poles to help the men who must climb them. As growth progresses, the lower leaves drop off, leaving the naked jointed stalk. At the maturity of the plant, only the leaves at the very upper end of the cane still remain. At this point a triangular-shaped tassel of blossoms sprouts from among those leaves. The natives say the plant "shoots a spike." When this happens, the planter knows that the cane is just about ready to be harvested.

The inside of the cane is soft, white, and spongy. As shown in Fig. 7, *A*, it consists of a mass of threadlike strings, or fibrovascular bundles, running through a spongy material similar to that found in the center of a cornstalk. This mass is saturated by a sweet liquid, the cane juice of commerce.

As sugar cane is a tropical plant, it demands for successful cultivation a hot, or at least a very warm, climate. It may be raised in regions near sea level between latitudes 35 degrees north and 35 degrees south of the equator. It must have a long growing season; a good, rich, loam soil; plenty of moisture, naturally or artificially obtained; and good drainage. Let us see why these things are so necessary.

It takes from nine to eighteen months for sugar cane to come to maturity. During the greater portion of that time the juice, which is to us the important part of the plant, has little if any sugar content. It is merely a watery sap whose purpose is to help the plant to grow by carrying food to all its parts. Not until the plant has reached maturity does the building up of the sugar content begin. At this time the plant is making more food than it is using, and so stores some of it away in the sap in the form of sugar. This process must continue for many weeks in the presence of sunlight and heat before the cane has stored enough sugar to be fit for cutting. There must be a warm season, then, of sufficient length to permit all these operations to go forward.

New cane crops are obtained in three ways: by planting seed, by planting suckers, and by what is known as the ratoon method.

Growing sugar cane from seed is not a popular method, because it is slow and unreliable. At the present time raising cane from seed is done chiefly for purposes of experiment in an endeavor to obtain new and possibly improved varieties.

The second method of obtaining a new cane crop is by planting suckers. You have learned that a bud, or sucker,

is found at each node, or joint, of the sugar-cane plant. A mature cane is cut into lengths of four or five nodes each. A shallow ditch, or trench, about four inches deep and three inches wide is prepared, and the severed sections of cane are laid in it horizontally, with the buds uppermost. They are then covered with two inches of dirt. In ten days or so the new plants begin to appear.

As you proceed with your studies in plant growth you will discover other plants that may be grown from single small sections of a "parent" plant. A piece of stem or root or even a leaf, under satisfactory conditions, may grow into a complete new plant. A few cells, adapting themselves to new conditions, become roots or leaves of the new plant. Such a method of reproduction, or production of new plants, is called vegetative reproduction to distinguish it from reproduction by means of seeds.

The third method of replacing a cane crop is by the use of ratoons. This term requires definition. When cane is harvested the stalk is cut to within one or two inches of the ground. The root system remains undisturbed. From this old root system other cane plants shoot out without further attention from any human agency. The new canes grown from the old roots of the previous crop are called ratoons. Cane raised by the ratoon method does not have the same high quality as the crop produced from suckers. It produces less sugar per acre. But the loss by lowering in quality is amply made up by the time and labor saved in planting. After several ratoons, however, the poorer quality is so marked that the old roots must be taken up and new canes planted.

Several destructive agencies work against the successful cultivation of sugar cane. Fortunately, however, they do not usually occur together; so enemies in one section are not troublesome in another. In Hawaii, for instance, the main attackers are the leaf hopper and the cane-borer, while in the West Indies the particular enemies are rats,

ants, hurricanes, and one kind of rot. Experiments in control are being made constantly, and so far the foes of sugar cane have been kept in check.

Cane is about 85 to 88 per cent juice and from 12 to 15 per cent fiber. The sugar recoverable from a given amount of the cane is from 10 to 15 per cent of the weight of its juice. These quantities vary according to the specimens used.

C. What Crops have been brought under Cultivation since the Beginning of History?

The crops which we have described, together with flax, rice, barley, millet, and a few others, have been cultivated in some part of the world since prehistoric periods. In some cases the original wild ancestor of the plant is unknown, although of course there must have been one. Nor do we know, except in a general way, how these plants came to be cultivated.

Let us now consider some crops which have been brought under cultivation more recently. Among the most important is the potato. White potatoes grew wild in tropical America before they were cultivated by the Indians. Several wild varieties are still found throughout South and Central America. Another is found in Colorado, bearing tubers, or potatoes, about the size of marbles. Potatoes were unknown in Europe until the sixteenth century, when they were carried back both by Spanish and by English explorers. Today as a world crop potatoes rival rice and wheat. About six billion bushels are raised each year.

Potatoes were raised by the Indians

The size of the potato has increased considerably under recent cultivation. Look at Fig. 8, *b*. A writer of the seventeenth century describes potato plants, then grown as a luxury in Virginia, as having potatoes "as large as a walnut and some larger."

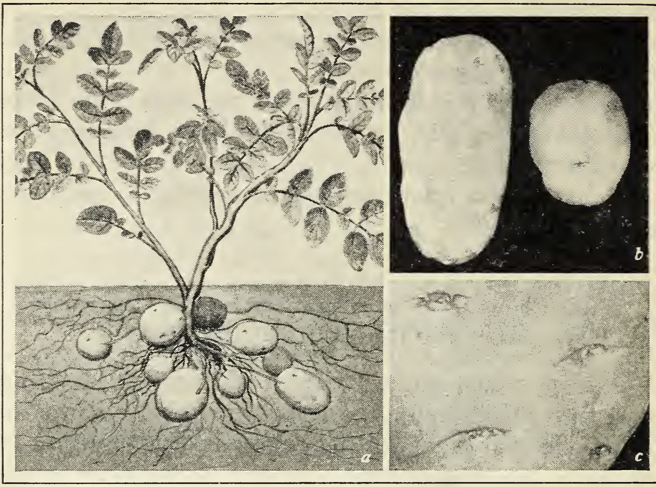


FIG. 8. The Size of the Potato has increased considerably under Recent Cultivation

a, the white-potato plant with its underground crop; *b*, relative size of the cultivated and the wild potato; *c*, a piece of potato showing eyes from which new plants may be grown

The white-potato plant shown in Fig. 8, *a*, develops slender underground branches, upon the ends of which grow the tubers, or potatoes. These tubers are swollen underground stems in which is stored starch made by the plant. The eyes of the potatoes are leaf buds.

It has been found that when the seeds from the flowers of a potato plant are sown, the seedlings almost always turn out inferior to the parent plant; they seem like their ancestor the wild potato. Consequently, potatoes are usually grown from cuttings, for which pieces of the tubers of the previous year are used. Each piece of tuber cut for this purpose must contain at least one eye. Each eye, as shown in Fig. 8, *c*, may produce a new plant. As in the case of sugar cane, a complete new plant will grow from just a small piece of the old.

American Sugar Beet Company

Fig. 9. The Juice of the Sugar Beet is an Important Source of Part of the World's Sugar Supply

At the left, the sugar beet; at the right, a crop of such beets ready for the harvest

Potatoes may be grown in regions too moist and cool for other crops of like food value. They also yield more calories of food per acre than most other crops.

Sugar beets, pictured in Fig. 9, offer an illustration of a crop that has been developed recently, a crop that was produced in answer to a very definite need.

Sugar beets were developed because of a definite need

In 1747 in Germany a chemist, Andreas Marggraf, discovered that beets contain sugar of the same chemical composition as cane sugar. This is sucrose, $C_{12}H_{22}O_{11}$, which we mentioned before. But beets can be grown in the temperate zone. What a find for the Germans! They could now produce their own sugar and be independent of the tropical crops of other nations. They lost no time in doing so.

At first the amount of sugar that could be extracted from beets was small. So men interested in the develop-

ment of better plants set to work to watch their beets closely and to select seeds each year from beets yielding the most sugar. Each year their beets became sweeter.

A pupil of Marggraf's established a sugar-beet factory. A generation later the Napoleonic wars, by cutting off cane-sugar sources of supply, made the industry grow at an unusual rate.

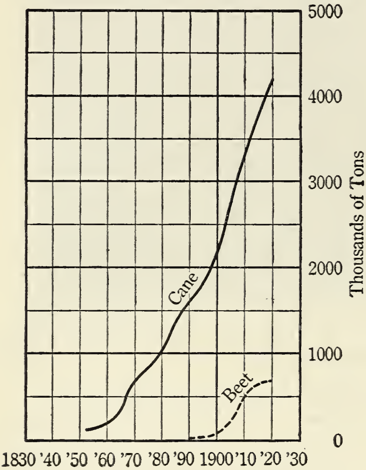


Fig. 10. The Use of Cane Sugar in the United States still leads that of Beet Sugar

Can you find any evidence here that man's use of sugar has increased?

The quantity of cane sugar produced in the world is about twice the quantity of beet sugar.

Fig. 10 shows increase in use of sugar in the United States since 1850. The population of the United States in 1850 was about twenty three million. Use was then at the rate of about 18 pounds a year per person. In 1920 the population was about 105 millions. In 1920 use of sugar was at the rate of about 92 pounds per person.

There are two important by-products from the sugar beets. These are the tops, and the pulp that is left after the juice has been extracted. Both are fed to cattle.

Rubber is another product of modern times. When Columbus came to America he found Indian children playing with rubber balls. He had never heard of rubber. But even if he had, even if rubber trees had grown commonly in the fields of Europe, perhaps no one would have found any very important use for them. Although we have dis-

Rubber is now raised on plantations

covered a surprisingly large number of uses for rubber, — rubber shoes, rubber coats, erasers, elastic goods, rubber cement, and many others, — it is the automobile that has made rubber a necessity. Some of the uses of rubber are due to the fact that it is waterproof; others to the fact that it is highly elastic.

Until shortly before the Great War most of the world's rubber was obtained from the rubber trees that grew wild in various parts of the tropics, especially in Brazil. Rubber trees belong essentially to the rain forest. They grow to large size and great age, but may be scattered through the forest at distances perhaps miles apart. In the early stages of the rubber industry the natives slashed the bark and collected the milky fluid which leaked out from the cuts. This they made into balls of rubber. For a while this process met the needs satisfactorily. But soon the demand for rubber became greater than the supply. Slave-drivers drove the natives without mercy; in the Belgian Congo especially the natives suffered tortures in the white man's attempts to keep up with the demand.

Something had to be done. There appeared to be three possibilities: another natural material might be found that had the same qualities as rubber; an artificial rubber might be invented; a greater supply of the familiar type of rubber might somehow be secured. All three possibilities were investigated.

The third method has so far proved the most successful. The British and the Dutch began to plant Brazilian trees in the East Indies. The outcome of the attempt was favorable. In the early 1920's a leading American tire-producer leased a million acres of land in Liberia, on the west coast of Africa, for the same purpose and with the same success. The British and Dutch East India plantations have been especially prosperous. In them the whole industry has been revised. The trees are planted close together so that long journeys from tree to tree are avoided.

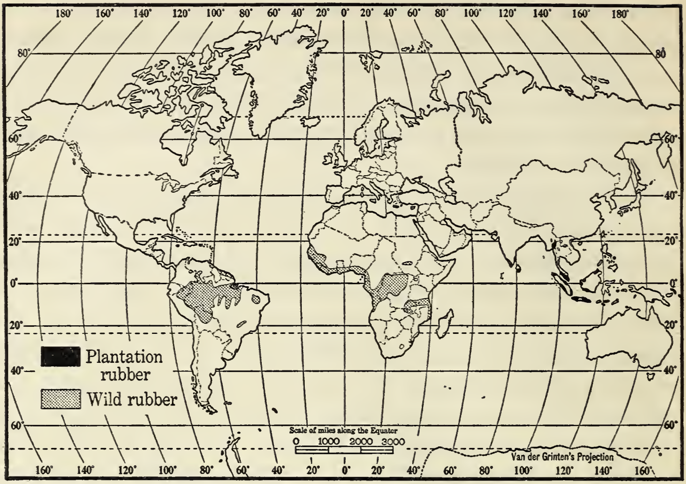


Fig. 11. Rubber is grown in Many Parts of the World Today

What nations control the principal output?

Trained rubber-tappers, intelligent and well paid, do the work formerly done by unskilled half-civilized savages. The old process of preparing the rubber has given way to modern methods that not only produce better rubber for the manufacturer, but produce it at a cheaper rate.

In the year 1934 the world used nearly one million tons of rubber. An increasingly greater part of the rubber comes from the cultivated trees. Today Brazil exports less than 5 per cent of the world's crop. In Fig. 11 is a world map showing the principal sources of rubber. What conclusions can you draw from it as to the conditions necessary for cultivation?

Parallel to a certain extent to the development that led to the production of plantation rubber is the modern production of quinine, which is made from the bark of the cinchona tree, shown in Fig. 12, *A*. These trees grow wild in the forests of Ecuador, Peru, and Bolivia, in the mountainous regions a mile or more above sea level.

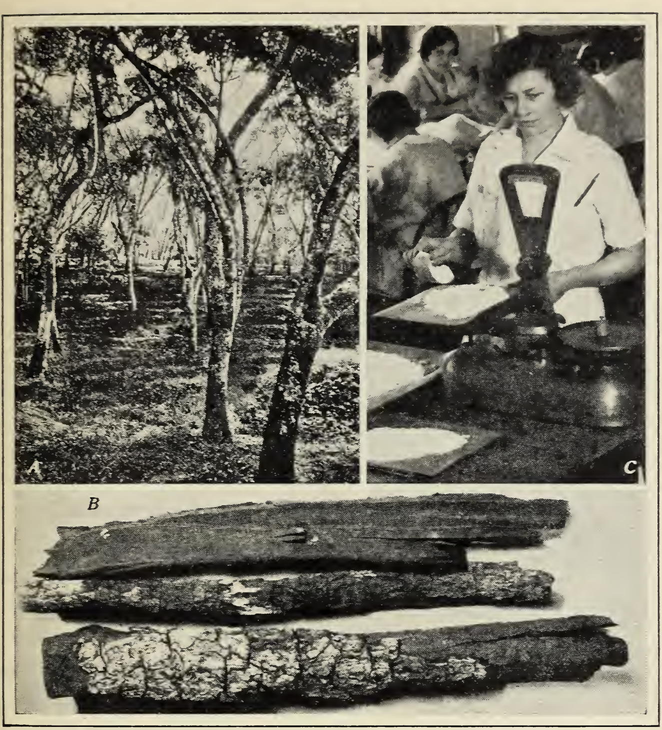


Fig. 12. The Cinchona Tree is now cultivated because of its Value in Medicine

A, cinchona grove; *B*, the bark from which quinine is extracted; *C*, quinine

Ever since it was discovered that quinine would cure malaria, the Indian natives have been hunting out cinchona trees, cutting the bark from them, and drying and selling it. As a result many of the trees have been destroyed. About the year 1860 some young cinchona trees were taken from South America by the Dutch and planted in the East Indies. Today the Dutch have almost complete control over the quinine market.

Keystone

Fig. 13. Blueberries are now grown in Cultivated Patches

Cultivated berries are better than wild ones

D. What are a Few of the Uncultivated Plants we use Today?

People who live in the country know a number of weeds that make good greens — better than spinach or beet tops, they say. Have you ever eaten milkweed boiled with a bit of salt pork? Do you know the taste of wild mustard, of the young spring shoots of brake ferns, of pusley, dock, pigweed, or cowslips? Glad indeed is the rural housewife when she can pick her first basket of wild greens in the springtime. And the city dweller who has never eaten them has missed a pleasant experience.

"Garden greens" are usually wild

There are blueberries too. Nearly all the blueberries in city markets are picked by women and children in patches located along the Atlantic seaboard. One is shown in Fig. 13. Perhaps during a summer vacation on a farm in New Hampshire or New Jersey you have armed yourselves with baskets, pails,

Most blueberries are wild

and sun hats and gone blueberrying. It is fun the first time you go blueberrying. It may be fun even two or three times a season; but if you are a country boy or girl, sent out day after day during July, August, and early September to fill a peck or perhaps a half-bushel basket in the hot sun, on the treeless slope of a hill or near a swamp with many mosquitoes and black flies buzzing around, you may not find it quite so much fun. You may wish that blueberry bushes were nearer together and that the berries were all big and sweet and thick upon the bush and easy to pick.

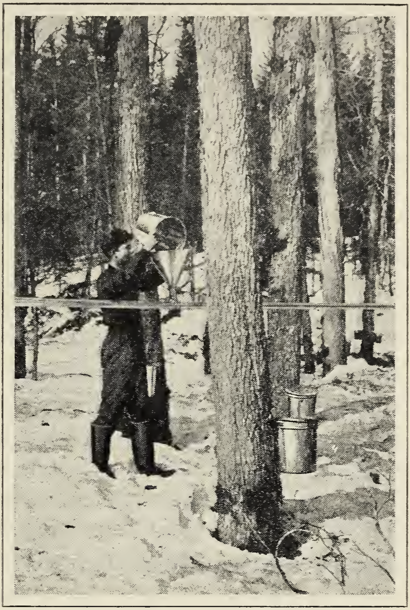


Fig. 14. Maple Sugar is boiled down from the Sap of the Sugar Maple

Notice the timesaving pipe line to the main sugar house

Some such day-dream is being turned into fact right now, for in certain limited areas blueberries are being cultivated. Cultivated blueberries are usually larger, sweeter, thicker on the bush, and much easier to pick than those found wild.

There is a product of the northern woods in which boys and girls are especially interested. This is maple sugar. Each spring, or perhaps only once in two years, boys and men go out to the sugar maples, also called rock maples, and drill holes, or "taps," in them, as shown in Fig. 14. At that time of year the sap is passing up and down the

sap ducts, or tubes, in the inside part of the bark of the tree. Some of it flows out through the taps and is caught in pails. When the sap is "boiled down," or evaporated, the sugar remains. As yet we have not found it worth while to cultivate these sugar maples in the same sense that we cultivate beets or sugar cane. Nevertheless they are well cared for and tapped only with moderation. A tree must be about thirty years old before it is large enough to be tapped.

Maple sugar comes from trees in the forest

The sap of a tree or other plant is the liquid in which food is circulated. The sap carries dissolved mineral substances absorbed through the roots from the soil. It also carries sugar and other soluble foods that have been made in the leaves. It carries them to other parts of the plant where they are needed for growth and energy.

Another wild-plant product of a different sort is chaulmoogra oil, already mentioned as a cure for leprosy. In the early years of the twentieth century British doctors in India noticed that the natives were using the oil from a certain seed to cure leprosy. It seemed to be effective. The doctors tried to find out where these seeds were produced. The natives either did not know or did not wish to tell. Finally, however, the seeds were traced to trees growing in northeastern Burma. Large numbers of seeds have been taken from these trees. The oil has been extracted from them and concentrated, and many lepers have been cured by means of it. But the supply is limited, and it is very hard to get at. So the next step in the conquest of leprosy appears to be more and more chaulmoogra trees in locations easier to reach. As in the case of rubber and cinchona this may mean plantations of chaulmoogra trees in the very near future.

A cure for leprosy comes from the forests of India

In this catalogue of plants you may be surprised that we have given little space to the trees that are used for lumber.

That is because they are of such importance that they must be considered separately in a later chapter.

These few plants that have been mentioned are of course only a small number of the wild plants of the world that are of value to man, but they will serve as well as a fuller list to illustrate a world-wide truth. Wherever and whenever plants have become economically important to man, he has sought ways of cultivating and improving them. He has studied their needs, their habits of growth, and their fruits. He has watched them and toiled over them in order to enjoy their products.

E. Why has there been an Increasing Need for Cultivating and Developing Plants?

There were few people in the Stone Age

Let us look backward for a moment. In the Stone Age, a hundred thousand years ago, there were very few people in the world. Even at the dawn of recorded history the human race probably numbered less than one million individuals, the population of a single large city today. These people could and did wander about from place to place. You have learned in your history classes about the huge waves of migration that followed one upon another in Europe. You know of much later migrations across the Atlantic, and of comparatively recent migrations westward across the United States. What has been the chief reason for this moving about? In nearly every case it was that food became scarce in the old environment or that the soil was worn out. What happened if there were people already living in the new lands? The roving tribe or nation killed them or made slaves of them and took their lands away from them. Not fair, you say? No, but true nevertheless. As man has spread over the face of the earth, he has carried with him seeds from his former homes and raised crops from them. In addition he has found new plants and new

kinds of seeds in his new homes. These he has used also. But they have not been enough for his needs. All the time he has schemed and struggled to raise larger crops on less land. The population increased. As people began to settle down and live in groups or communities, fewer of them were killed; for farming is a less dangerous occupation than hunting. Individuals lived to be older and produced more young, who in turn lived to maturity.

By the dawn of recorded history there were perhaps more people in Egypt alone than there had been in all the world in the Old Stone Age. This population was supported from the wheat and other grains raised along the fertile banks of the Nile. Today the population of the world is in the neighborhood of 1,900,000,000 — nearly two billion mouths to be fed, two billion bodies to be clothed and sheltered. It takes a lot of wheat, a lot of corn and potatoes, sugar cane, rice, cotton, and lumber to do the job! With increase in population there has come an increase in food production. Today there can be plenty for all and apparently more than we need.

Today the world's population is close to two billions

But still the population increases. Predictions have been made at various times that the world's growing population will soon be checked by the limits of its food supply. At present it would seem that better and better methods of raising crops make these predictions incorrect.

Wild plants have been cultivated (1) because increased demands have been too great for the natural supply, (2) so that a nation would be independent of other nations, (3) so that the supply might be near at hand, (4) because the cultivated product could be made superior to the wild product. As population has increased, there has come the need for more food and other plant products. Today the earth supports nearly two billion human beings.

Can You Answer these Questions?

1. What changes took place in man's methods of living after he learned to cultivate plants?

2. Was the food of prehistoric man more or less varied than the food of today? Why do you think so?

3. What factors in the development of the cotton plant help to explain why cotton is not grown in all parts of the United States?

4. What are the principal reasons why sugar cane requires a very warm climate and a long growing season?

5. What are the three methods used for securing new crops of sugar cane? How do they differ from each other?

6. Why are sugar cane and potatoes, as well as some other crops, raised from cuttings rather than from seeds?

7. Why has plantation rubber largely taken the place of wild rubber during the last generation or so?

8. What are some reasons why the population of the world has increased so greatly in the last few thousand years?

Questions for Discussion

1. What economic importance is there in the fact that the United States owns about 85 per cent of the world's automobiles and yet controls less than 1 per cent of the rubber output of the world?

2. It has been said that man today can raise more than sufficient foodstuffs to supply the needs of all. Do you believe that this is so? If it is, why should we have thousands of people hungry and even starving? Why should many people be undernourished?

3. Chemists have found a substance called saccharine, which is three hundred times sweeter than cane sugar. Why does not man use this rather than go to all the trouble of producing cane or beet sugar?

4. What evidence can you think of which would support the statement that agriculture is more ancient than history?

Here are Some Things You May Want to Do

1. Make a study of some of the plants cultivated by the American Indian. Read *Columbus came Late,* by Gregory Mason.

2. Make a wall chart showing the original homes of various cultivated crops. You may get some help from Parker and Cowles's *Book of Plants.*

3. Make a list of plant products used in medicine. Ask a druggist to help you. You might like to report to class on some of the things you have found.

4. From time to time man has tried to find new sources of rubber supply. Among the plants he has tried to use are the milkweed and the Mexican plant called guayule. See what you can find out about man's success along these lines. Possibly you may find some other plants which he has tried to use.

5. See if you can find out why wheat has been called the "staff of life." Should you say that this is true today? Your findings might be presented in class as a talk or as a written report. You might wish to prepare a number of graphs showing the relative importance of wheat and corn as two of our principal cereal crops in comparison with other grain crops. You can secure your information from various references, including the World Almanac and the Statistical Abstract of the United States.

6. Count the number of eyes in a potato. Place this potato in moist soil in a warm place. Keep the soil moist but not too wet. Observe the relationship between the number of new plants and the number of eyes. As the plants grow, what happens to the old potato?

7. Plant a sweet potato in a similar manner. From what part of the potato do the new plants come? What is the function, or purpose, of the food stored in the sweet potato?

8. Place clippings of willow or poplar in a bottle of water. Could you produce new trees by this method?

9. Place some cuttings of geranium or begonia in moist sandy soil. Cover the soil to prevent drying. Can you produce new plants in this way?

Chapter II · How have we developed New Plants and New Varieties of Plants?

"*New ten-thousand-dollar nasturtium goes to flower shows in Europe.* Plant winning highest honors in United States to be exhibited in Holland, France, and London. Burpee double hybrid developed in eleven months." This news item appeared in a leading paper one spring day in 1934.

In the same paper, several pages later, there were these "garden notes."

Sweet-scented gladioli produced by scientific breeding after many years of failure. The popular gladiolus has added a new success. Scarce half a century ago an obscure small-flowered winter bulb grown chiefly in greenhouses, today in diversified colors and forms it is one of our most popular outdoor flowers. These latest hybrids have the beauty of our best garden varieties and the pungent scent of their wild ancestors.

Dwarf iris blooms in autumn. Iris growers, by careful selection of types, have produced midgets for rock gardens, giants for shows, and new varieties in color. Now hybridizers produce varieties that bloom in autumn.

A. What are Hybrids?

What do we mean by *hybrid*? A hybrid is a plant or an animal derived from the crossing of two distinct varieties. Can man produce new plants or new varieties of old plants, then, with any desired characteristics, or traits, whenever and wherever he may wish?

Hybrids are of mixed parentage

The idea is not new to you. You may have observed the crossing of red and white corn or of field corn and pop corn. The resulting plants are hybrids. They have some of the characteristics of both parents but are unlike either. Plant experts have tried many kinds of experiments in crossing. They have produced hybrids by crossing potato and tomato plants. Some

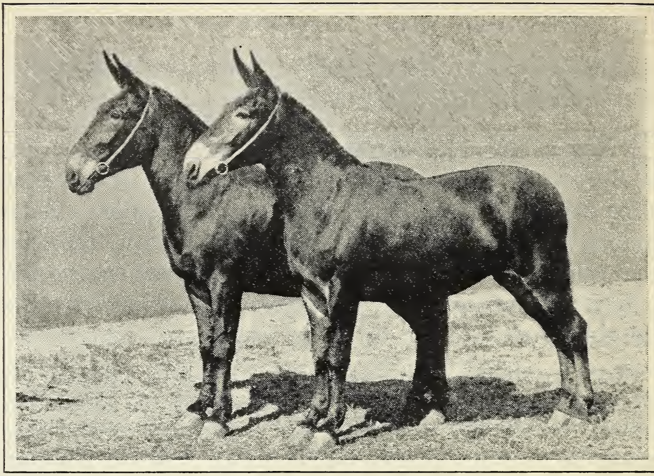


Fig. 15. Mules are Hybrids

Can you find any resemblances to their parents?

of the freaks thus obtained grow potatoes above ground and a fruit like tomatoes under ground, but others, alas, grow neither! Gardeners have crossed petunias and tobacco plants, with results that were apparently worthless. They have produced new hybrid wheats, hybrid grapefruits, hybrid walnuts, far superior to the parent plants. They have made improvements to suit a wide variety of human needs.

There are hybrids also in the world of animals. The mules (shown in Fig. 15) are hybrids — their mother a mare, their father a jackass. Wild zebras have been mated with horses, and wolves or foxes not infrequently mate with dogs.

Hybrids are sometimes, but not always, incapable of producing offspring, that is, others of their kind. In the case of plants they may lack seeds entirely. If they do produce seeds, however, these seeds are likely to result in still more varied specimens, unlike either parent and perhaps unlike the grandparents.

Another very important way in which new types arise is by a process called mutation. A mutation is a change. The organism produced by the mutation is called a mutant. Mutants are produced by variations which suddenly appear in the organism, and they have nothing to do with cross-breeding. Mutants, or "sports," will breed true to type, and in this way many new varieties are formed. For example, the Ancon breed of sheep, a short-legged type, arose suddenly as a mutant in a normal flock of sheep.

Since man has little or no control over the production of mutants, this matter will not be considered at length in this chapter.

B. How are Hybrids Produced?

Hybrids may result under natural conditions

Natural hybrids may appear when plants or animals of two closely related groups that will interbreed live fairly near together. Such hybrids are being produced all the time. Many of them are less well fitted to the environment in which they find themselves than are their parents. More often than not they die without leaving any descendants. But occasionally there appears a hybrid that is better adapted to its environment than either of the two groups of plants or animals to which its parents belonged. In this case it will probably live and may produce offspring. Some of the offspring may be superior individuals. These superior individuals may in turn produce other superior individuals. A succession of superior individuals may within a few generations crowd out the older stock altogether. Hybrids, of course, usually do not breed true to type. However, if the hybrid type happens to fit the particular environment better than the parent types do, then it may endure, whereas the parent types may be crowded out; that is, natural selection occurs. There are illustrations of such successful natural crosses in the different varieties of pigeons, butterflies, primroses, wheat, blueberries, and ducks.

Another successful hybrid, the London plane tree, which is now commonly sold by nurserymen in America under the name of Oriental plane, is supposed to be a natural hybrid between our native sycamore and the true Oriental plane. It is an especially rapid grower and makes a good shade tree for city streets.

What lies behind this process of hybridizing? What makes any offspring, either plant or animal, what it is? In your earlier work in science you learned that with few exceptions, and these among the lower forms of life, an individual plant or animal has two parents, one male and one female. Each parent contributes certain characteristics to the sum total of characteristics of the offspring. Consider a chick whose father was white and whose mother was red. The chick might be either red or white. All would depend upon the workings of heredity. Or consider a grain of wheat produced as a cross between two well-known varieties, Red Fife and Hard Red Calcutta. It might produce a plant that would ripen early like the Calcutta and yield abundantly like the Red Fife. It might, on the other hand, produce a plant that would ripen late like the Red Fife and yield little or nothing like the Calcutta. In either case its characteristics would be inherited from its parents.

An individual has two parents

The structures for passing on the characteristics from one generation to the next are found in the egg cell and sperm cell which unite to form a new individual. In a flowering plant the sperm cells are carried in pollen grains. The egg cells are contained in the ovules which are located in the ovary at the base of the pistil. Before a seed can be produced, a sperm cell from a pollen grain must combine with the egg cell within the ovule. This combination produces a fertilized egg, and from the fertilized egg the seed develops. Under normal conditions a new plant will grow from the seed.

Hereditary characteristics are carried from one generation to the next

The parts of a flower are shown in Fig. 16. Pollen is produced in the anthers which form on the ends of the stamens. The end of the pistil is the stigma. The ovary is the enlarged base of the pistil. The process by which pollen is transferred from the anther to the stigma is called pollination. The process in which sperm cell and egg cell unite is called fertilization. Obviously pollination must take place before fertilization can take place.

Some flowers may be self-pollinated; others are always cross-pollinated. In self-pollination the process takes place by the transfer of pollen from the anther of one flower to the stigma of the same flower. In this case the sperm cell and the egg cell with which it combines are both produced by the same flower. In cross-pollination there is transfer of pollen from an anther of one flower to the stigma of another. In this case the sperm cell and the egg cell with which it combines are produced by different flowers. These two processes are illustrated in Fig. 16. In the study of heredity and plant-breeding it is important to see clearly the difference between cross-pollination and self-pollination.

Some plants are self-pollinated

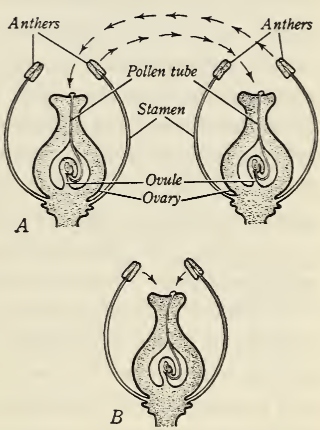
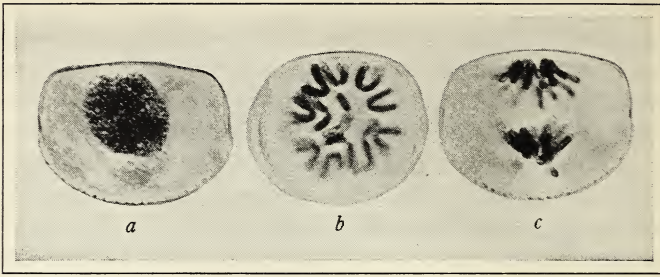


Fig. 16. Some Flowers may be Self-pollinated; Others are always Cross-pollinated

A, cross-pollination; *B*, self-pollination

Within the sperm and egg cells are the carriers of heredity. They are the chromosomes. They may be seen and counted with a good microscope. Fig. 17 is a photograph showing chromosomes. Omitting from consideration the sex-determining chromosome (a special case), each sperm



Arnold Arboretum

FIG. 17. The Chromosomes are Carriers of Heredity

a, the nucleus, or center containing the chromosomes; *b*, the chromosomes about to divide; *c*, the separation of chromosomes to form two nuclei. How many chromosomes are there in *b*?

cell and each egg cell from the same kind of plant have the same number of chromosomes. For example, the sperm in the pollen of field corn contains ten chromosomes. The egg cell also has ten. The fertilized egg contains the chromosomes from both sperm and egg. It therefore has twenty chromosomes. Within the chromosomes are the determiners of hereditary characteristics. Some field corn, for example, matures early, produces red ears which are long and slender, and has other peculiar characteristics. Other corn matures late and produces white ears that are short and thick. The determiners of these characters are called genes, and the genes are carried in the chromosomes. Now suppose that a sperm cell from pollen of one kind of red corn combines with an egg cell from the same kind of red corn. The genes from both sources are determiners of the same kind of characteristics.

Genes are determiners of hereditary characteristics

The ears of corn produced from this combination will be like the parents that produced the sperm and the egg. But suppose sperm cells that carry chromosomes with genes for whiteness, thick and short ears, and late maturing should combine with egg cells that carry genes for redness,

In cross-pollination genes of different kinds may be mixed

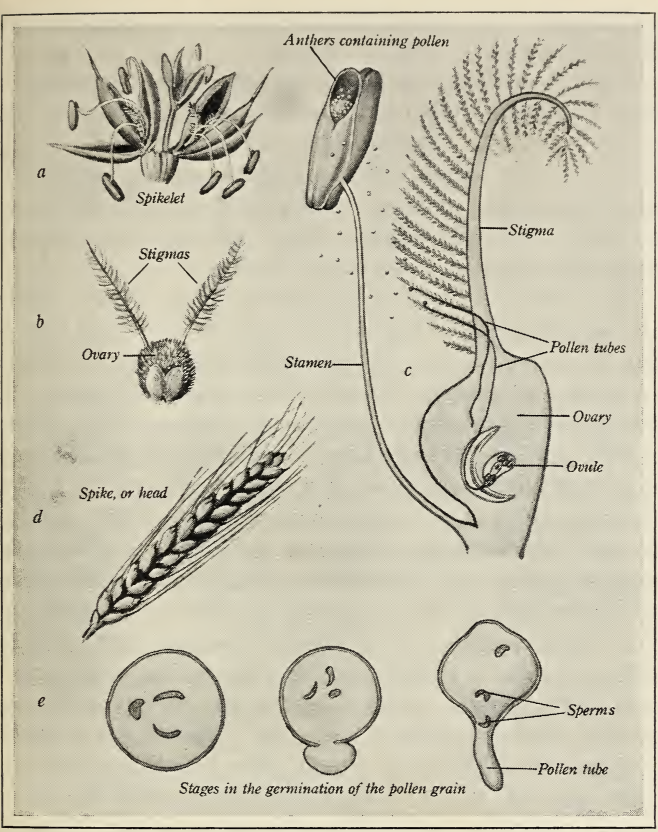


FIG. 18. The Wheat Flower is Normally Self-Pollinated

a, the spikelet is a cluster of flowers; *b,* each flower contains a pistil; *c,* pollen from the anther falls on the stigma; *d,* the grains of wheat form in the spike or head. (Notice its bearded appearance. Some wheat is not bearded.) *e,* the pollen grain forms a pollen tube which carries the sperm to the egg

long ears, and early maturing. What should you get? Obviously there would be a mixing of genes. You might get red corn with short ears, you might get white corn with long ears, or you might get other combinations. The aim

in plant-breeding and animal-breeding is to bring together genes for desirable characteristics.

Now let us study some of the processes by means of which desirable kinds of wheat have been produced. The process is simpler than in some other plants, so we may study it at some length. Wheat is commonly self-pollinated; but pollen grains may be carried by the wind, and cross-pollination does sometimes occur. In experimental work cross-pollination may be easily done.

The parts of a wheat flower are shown in Fig. 18. When the spike, or head, of wheat first appears, it may be seen to consist of a number of spikelets (Fig. 18, *a*), each of which is a cluster of, usually, three or four separate blossoms. In each blossom there are a number of stamens with anthers on their outer ends and there is a pistil with flowery stigmas. The pistil, separated from other parts of the flower, is shown in Fig. 18, *b*. A cross section of the flower, showing the pistil and a stamen, is shown in Fig. 18, *c*. This shows how pollination and fertilization may occur. Pollen from the anther falls upon a branch of the feathery stigma. A cross section of the pollen grain is shown in Fig. 18, *e*. Pollen, as soon as it falls on the stigma, begins to grow a tube. This growth continues until the tube reaches the egg cell within the nucleus, or center. The sperms, of which there are two within each pollen grain, pass down this tube to the egg cell. One of these sperms unites with the egg to produce a fertilized egg. The other sperm is lost. The fertilized egg forms a seed. Soon after fertilization occurs, the fertilized egg begins to divide. First, it divides, forming two cells. Then each of these divides, forming four, and so on until a large number of cells are formed. Food for growth of the new cells is carried to them from the green cells where it was made. Gradually the process of cell division goes on more slowly. The seed ripens, and life activities within the cell almost cease. Each seed on the spike, or head, of wheat starts in this

A seed forms from a single cell

way. Bear in mind that wheat is normally self-pollinated but that in experimental work it may be cross-pollinated.

Life will continue in the cells of the seed for a long time. When the seed is planted in warm, moist soil, cell division begins again. There are cells that form roots, others that form stem and leaves, and in a little time there is a plant equipped to make food, to grow, and to produce new seeds. The process is complex, but in your later work in the senior high school you may learn how the hereditary characteristics are carried from the single egg cell contained in a flower through all the many changes that take place as a seed is formed and grows into a new plant. Obviously these characteristics are carried, for a wheat seed will produce a wheat plant which is like the one from which it came. It will be like it in very particular ways. The seeds will have similar shapes. The wheat of one season will ripen in about the same time as was required for the same kind of wheat of the previous season. It will resist parasites, such as wheat rust, just about as effectively as the parent plant did. And so on. Wheat, as well as other plants and animals, has many definite hereditary characteristics.

Suppose we consider now some different kinds of wheat. There may be one that produces well, but grows only in a warm climate. There may be another that produces poorly, but will grow in a cold climate. Is it possible to mix the genes of these two kinds of wheat so as to get a wheat that produces well and that will live in a cold climate? Plant-breeders in the Department of Agriculture at Washington, D.C., have attempted to answer this question and many other questions. Some years ago they tested more than a thousand different varieties of wheat obtained from many different parts of the globe. There was one that had been imported from southern Russia. It was hard and difficult to grind, but it was fairly well adapted to grow in the dry lands of the Western Plains. It was a variety of winter

In plant-breeding desirable characteristics are brought together

wheat. Winter wheat is planted in the fall. The seeds sprout and green leaves form before frost comes. Cold weather kills the green leaves; but if the winters are not too severe, the plants remain alive in the ground till spring. When warm weather comes, they start to grow and by early summer have produced a crop. This wheat could be grown in Kansas, but it could not be grown successfully in Montana and southern Canada. It could not live through the severe winters. There was a real need for a wheat that would grow to maturity and produce a good crop during the short summer season of the Canadian agricultural regions.

Winter wheat is sowed in the fall

Let us tell you the story of one kind of wheat that was developed to meet the conditions of western Canada. The Marquis wheat is a hard red spring wheat, more popular in Canada today than any other kind, and yet it was first produced only a little over thirty years ago. It is called spring wheat because, unlike winter wheat, it is planted in the spring and matures during the summer. It does not live in the ground through the winter.

In the wheat fields at that time there was grown a variety of spring wheat called Red Fife. It yielded abundantly, produced fine white flour, milled easily, and baked well. It was — and still is — popular in our own West. But it ripened slowly, and in the years when frosts came early the Canadian farmers lost heavily. Two or three years of early frosts in succession brought financial ruin to them. No wonder that new farmers were afraid to settle on the rich but cold lands of Winnipeg and Manitoba.

Then a few practical wheat-growers began to experiment. They looked about for a sturdy wheat plant that ripens very early. They found it in the Hard Red Calcutta from India. Now this Red Calcutta was in other ways inferior. It yielded very little wheat, and what little it did yield was of poor quality. But the experimenters took some plants of Red Calcutta and used them as mother plants. They

selected pollen from the Fife. This pollen they brushed carefully upon the pistils of the Red Calcutta, having previously covered the blossoms to protect them from any pollen that might be carried on the wind. After the plants had been pollinated from the Red Fife, they were again carefully covered and the seeds allowed to develop. All these seeds were sown, and the hybrid seedlings came up. Such a varied lot! Some were tall, some short. Some had fine big heads; others small heads. Some could resist the disease called wheat rust; others were covered with it. Seeds from the plants that ripened earliest were saved, for this characteristic was the one especially desired for the new wheat.

When the second season came, these selected hybrid grains were sown. A more mixed lot of seedlings came up than the crop of the first year! But among them were a few plants that matured early and yielded well. The seeds of these plants were saved and sown again, and all the plants raised from this seed yielded abundantly and ripened early. The experiment was a success!

Marquis wheat was *made* for Canada

The new wheat thus developed was named Marquis. It is a good wheat for the western part of Canada. It had been produced especially for that environment. During the World War England depended largely upon Canada for her wheat supply. The demand was met chiefly through the exportation of Marquis wheat.

North Dakota apples are adapted to conditions there

For an example of a tree produced to meet a definite need let us look at the apples in North Dakota. Here the winters are severe, but the summers are hot. Early settlers had difficulty finding a tree which yielded well and which would at the same time live through the cold winters. One man planted thousands of apple seeds each year of his life until he found a tree that met his needs. This single tree, through the process of grafting, has become the parent of nearly all the apple trees in the state.

Fig. 19. Many Hybrid Plants may be produced by Careful Selection and Breeding

The giant chrysanthemum at the left is a hybrid; those at the right are not

Many other illustrations may be given. For years and years the Chinese and Japanese have produced hybrid chrysanthemums, asters, and peonies. The giant blooms of chrysanthemum shows may be first cousins of the tiny buttonball varieties in your garden. Indeed, if the seeds of both were sown side by side, you could not tell which seedlings were the offspring of which plant. Most of them, in fact, would look like common wild daisies, the distant ancestor of them all. The splendid "giant hybrids" are produced from slips or cuttings, once they have been developed. Compare the two chrysanthemums shown in Fig. 19.

Highly developed hybrids are reproduced from cuttings

These experiments with wheat show how man has learned to control the wheat supply. Similar controls have been accomplished with about all food-producing plants, until cultivated plants are indeed quite unlike the wild ancestors of which they are descendants.

C. What Principles Control the Production of Hybrids?

Are there any general underlying principles which plant-breeders have learned from their observations of or experiments with hybrids?

More than sixty years ago in his garden in Moravia a monk, Gregor Mendel, discovered some facts that help us in predicting many things about hybrids. Let us follow some experiments with the garden flower known as the four-o'clock. There are two common varieties of four-o'clocks. One has red blossoms; the other has white blossoms. In other ways they are alike. Suppose we take two plants, one of each variety. Now let us carefully pollinate the pistils of the white flowers with pollen from the red ones and the pistils of the red ones with pollen from the white.

In the course of time seeds develop. We plant them and await results. The plants begin to come up. For a while they all look much like their parents. Then the blossoms appear, and here we notice something new. *All* the plants produce pink blossoms! These plants are called first-generation hybrids. Now let us plant their seeds and see what happens. In the second generation we still have some pink blossoms; but we also have red blossoms and white blossoms, as we had in the grandparent plants. In what proportion do these colors occur? About half the plants bear pink blossoms, about a fourth bear red, and about a fourth bear white. Now let us plant these seeds.

Let us put them in three different gardens: the pinks in one, the reds in a second, and the whites in a third. The pinks are pollinated with pinks only, the whites with whites only, and the reds with reds only. We are now dealing with third-generation hybrids. Again all the plants look alike until it is time for them to blossom. And then?

From the seeds of red flowers we have all red blossoms. From the seeds of white flowers we have all white blossoms.

FIG. 20. GREGOR MENDEL, *whose Hobby was Gardening* (*1822–1884*)

GREGOR MENDEL was an Austrian peasant boy when he entered the monastery at Brünn, which was then in Austria but is now part of Czechoslovakia. He was a brilliant youth, rather short and heavy, with a beaming smile and a high forehead. It was not many years before he became head of the monastery · The quiet life in the monastery gave him leisure to have a garden, to which he was so devoted that he referred to the flowers as his "children." For many years he worked in his garden, and his nearsighted blue eyes proved excellent for painstaking observation. Gardening became his hobby · In the year 1865, on a cold winter evening, he read before the little scientific society in the town a paper reporting his observations. It was on the inheritance of various characteristics in garden peas. The results had been reduced to the accuracy of mathematics. His friends listened, probably, as most people do at lectures. But no one was especially impressed. No one seemed to care very much whether peas bred true or not. What difference could it make? · Twenty years later the monk Mendel died, respected and loved by a small circle of associates but almost unknown in the scientific world · Sixteen years after that, Hugo De Vries, then studying heredity in general, dug up Mendel's old papers and diaries, checked over the observations, compared them with his own, and found that they agreed in principle. In 1900 two other scientists independently discovered the same laws. Thus the long-forgotten monk became a man of note in modern biology. Gregor Mendel had lived and died a generation too soon.

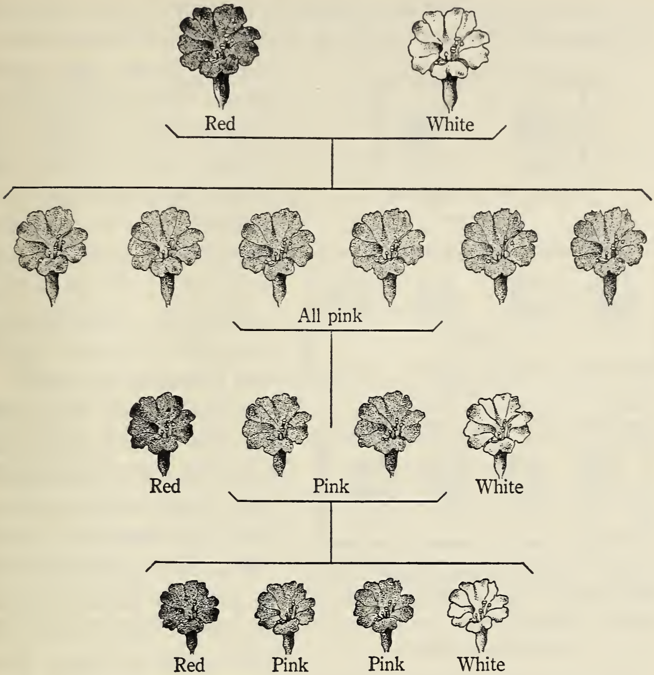


Fig. 21. Certain Natural Laws control the Production of Hybrids

Read your text again and explain in terms of Mendel's first law why the pollination of red and white four-o'clocks should result in the hybrids shown above

But from the seeds of the pink we have red, pink, and white. And they appear in the ratio of one red, two pinks, and one white, exactly as they did in the second generation! If we should continue the experiment, we should find that the reds will produce only reds when pollinated with reds, that the whites will produce only whites when pollinated with whites, and that the pinks when pollinated with pinks will produce red, pink, and white flowers in the ratio of 1, 2, 1. This illustrates Mendel's first law. Fig. 21 shows these relations.

Mendel's first law: 1 to 2 to 1

Now take another case, that of varieties of peas. Mendel experimented with a variety having yellow seeds and a variety that had green seeds. He crossed them, as was done in the case of the four-o'clocks. All the hybrids of the first generation were yellow! These were crossed with each other. Of the second generation, three fourths produced yellow seed; one fourth green seed.

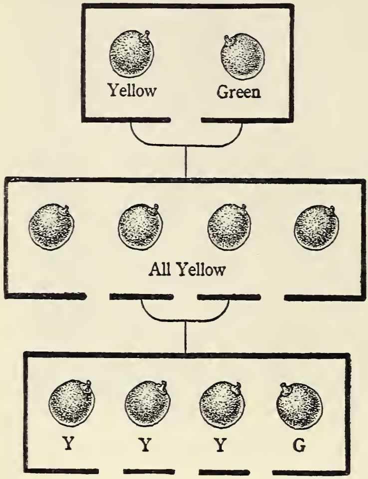


Fig. 22. Certain Characteristics of Hybrids may not appear in the First Generation, although they may appear in Later Generations

Is this true of the peas shown in the sketch above?

These seeds were now planted in their turn, and each was self-pollinated. The green seeds continued to produce green seeds from generation to generation unless further crossed. But of the yellow seeds a third produced only yellows. The other two thirds produced mixed crops in the same ratio as in the second generation — three yellows to one green. Study Fig. 22. This case seems more confusing than the case of the four-o'clocks. Can it be explained?

From his many years of work Mendel drew the conclusion that some characteristics tend to show up in hybrids while others do not, but that these others are present and may appear again in the next generation. He called the characteristics that show, *dominant*; those that do not show, *recessive*. Let us suppose for a minute that this was the case with the pea seeds and see if the explanation fits. Here we have

Traits may be dominant or recessive

yellow and green cross-pollinated. The offspring of the hybrids, according to Mendel's first law, should appear:

Pure Yellow	Mixed (Yellow)	Mixed (Yellow)	Pure Green
yellow yellow	yellow green	yellow green	green green

In the four-o'clocks we had:

Pure Red	Mixed (Pink)	Mixed (Pink)	Pure White
red red	red white	red white	white white

The four-o'clock "mixed-breeds" appeared pink. The pea "mixed-breeds" *appear* to be yellow. Here the green does not show at all. But when these seeds are planted, some of the next generation have green seeds.

Characteristics of a parent which do not appear at all in first-generation hybrids are likely to show in the second generation. All such characteristics are said to be *recessive.* Characteristics which show in the first-generation hybrids are said to be *dominant.* In the peas green in the seeds is apparently a recessive trait while yellow is dominant. With the four-o'clocks neither color was dominant.

Pure stock breeds true

A "pure dominant" always breeds true. A "pure recessive" breeds true. But the hybrids which *look* like the pure dominants breed in the ratio of 1 to 2 to 1. Further, a first-generation hybrid is like its dominant parent or of an intermediate character, as in the case of the four-o'clocks. The "pure dominants" of the second generation cannot be discovered from the appearance of the seed.

When this law is understood by a plant or animal breeder, he knows what to expect from his hybrids. He knows that the second-generation individuals may be different from the first and that the third may be different from the second.

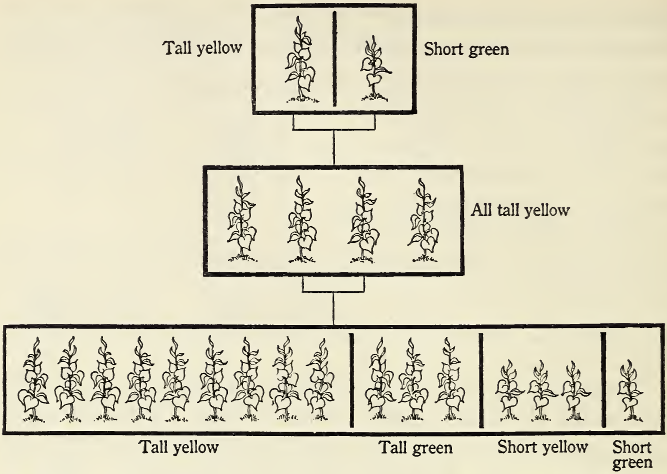


FIG. 23. The Law of Dominant and Recessive Traits is illustrated by the Results of Breeding shown Above

What dominant traits can you find? What recessive traits?

Mendel's second law has to do with cases where there are several different characteristics to be considered. Let us take the peas as an example. The yellow seeds in Mendel's experiment happened to grow on tall vines. The green seeds grew upon dwarf vines. Suppose we look at the vines as well as at the seeds in the hybrid plants.

Different traits are inherited independently

Yellow and tall are both dominant; so in the second generation all plants are tall and produce yellow seeds. But in the third generation a quarter of the plants have green seeds, and a quarter of the vines are dwarf. Three quarters have yellow seeds, and three quarters are tall. The ratio in which these two characteristics appear together is shown in the plants of Fig. 23. Count them. There are mostly tall yellows. These are combinations of dominant characteristics. There is only one short green. This is a combination of recessive characteristics.

Mendel's laws were the result of many experiments. They have been more fully explained recently through the discovery of chromosomes and an understanding of their nature. You remember that at the beginning of this chapter we told you about the chromosomes in the egg and the sperm cells and mentioned the genes believed to be carried by the chromosomes. The genes are so small you cannot see them. Their existence is indicated by the behavior of the chromosomes. These genes are the units which determine the characteristics of any living thing. One gene may determine color, another height, another the shape of a particular part, and so on. From generation to generation these genes and the chromosomes that contain them get shuffled about and redealt. You never saw two living things exactly alike. That is because the combination of genes that determines the characteristics of any individual is probably not duplicated elsewhere in creation.

Genes within chromosomes determine traits

Let us summarize briefly. Certain characteristics in plants and animals tend to show up in hybrid offspring in the first generation. These are said to be dominant. But the appearance of the first-generation hybrids is no guaranty that their offspring will be like them. In addition, when two or more different factors enter a cross, as color and "tallness," they are distributed independently in the germ cells of the hybrids in the ratio of 3 to 1.

D. How may Desirable Characteristics be Kept?

When the North Dakota farmer obtained the apple he wanted and the Canadians the Marquis wheat, how did they keep on producing these desirable varieties?

There are two principal ways. The first is by taking a part of the plant itself and causing it to grow. The second is by breeding for "pure recessives" or "pure dominants" and then keeping the stock from becoming crossed. You

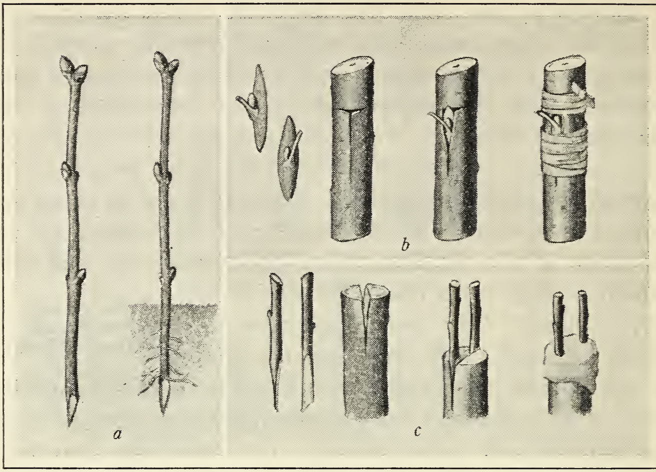


FIG. 24. Plants may be reproduced in Various Ways

a, slipping; *b*, budding; *c*, grafting

have seen how this second method might be used in the case of tallness and color of seeds in peas.

Have you heard the terms *cutting, grafting, budding, slipping,* as applied to plant reproduction? Suppose it is an elm tree, a willow tree, a forsythia bush, a white potato, or a geranium that you wish to reproduce. You do not need to wait for seeds to plant. Besides, seedlings too often produce inferior plants, like their distant ancestors. You simply take a cutting, or slip, from the parent plant, as shown in Fig. 24, *a*. This you trim back and set out in wet peat moss or moist sand or even in damp earth. It will soon develop roots and proceed to grow. It will be like the parent plant because it *is* the parent plant. It is in truth "a chip off the old block."

Vegetative reproduction insures new plants like their parent

Not all plants will root from cuttings, but many will. A few others may be rooted from single leaves. Still others may be grown by grafting a small shoot or bud upon an-

other plant of the same family. This is the way that apples and roses are usually grown. Some illustrations of kinds of budding and grafting are shown in Fig. 24, *b* and *c*. The ungrafted branches are cut off. Thus the apple or rose of superior characteristics may be grown upon the roots of a sturdy but undistinguished member of the same family.

Plants that have developed naturally have not in all cases fitted man's needs. Therefore he has produced new varieties by crossbreeding. Study of the Mendelian laws makes scientific crossbreeding possible. Characteristics may be dominant characteristics appearing in first-generation hybrids. In the second-generation hybrids traits appear in the ratio of 1 pure dominant to 2 hybrids to 1 pure recessive. Many different traits may be inherited at the same time, but each is inherited independently of the others. Desired characteristics once obtained in a stockmay be maintained by preventing further crossbreeding or by means or reproduction from grafts or cuttings.

Can You Answer these Questions?

1. What is a hybrid?

2. How does cross-pollination differ from self-pollination?

3. How does a recessive character differ from a dominant character in the way that it is inherited?

4. Why are no two individuals in the world exactly alike?

5. May hybrids be produced under natural conditions, or are they always produced artificially? Be prepared to defend your answer with examples.

6. Are hybrids ever suited to growth in a region where the original plants could not live?

7. What is the relation of chromosomes and genes to inheritance? Can genes be seen with a microscope? Can chromosomes?

8. Can you trace the steps in the fertilization of wheat?

9. How may Mendel's first law be used to explain the observations made on the four-o'clock plant?

10. What evidence is given in this chapter that careful seed selection may be of great economic value?

11. What are the essential differences in cutting, slipping, budding, and grafting, as applied to plant development?

Questions for Discussion

1. You may have seen a horse-chestnut tree with one branch having white blossoms and all the other branches having pink blossoms. Can you explain what had happened?

2. Is it possible for an apple tree to produce two different kinds of apples? Explain.

3. Would it be possible to hybridize corn and sugar cane so as to produce a crop valuable for all the things that corn is used for and also for all the things that sugar cane is used for?

4. Is it possible to say in all cases that mixed breeds are inferior to pure stocks or the reverse? What factors should you have to consider before you make your answer?

5. Does planting two varieties of a plant side by side tend to produce hybrids? Explain your answer.

Here are Some Things You May Want to Do

1. Make a study of some of the work done in improving wheat or some other plant. Your neighborhood florist or nurseryman might be able to help you.

2. Luther Burbank was famous for his experiments with plants. Find out what you can about his work and report on it in class.

3. On one of your field trips make a collection of leaves from some species of tree and bring them back to class. Let each member of the class take any twelve leaves and measure them for their length along the stem from the tip to the base. Make the measurement in centimeters. Construct a table showing, within five millimeters, the number of leaves of each length. Construct a graph showing the results of the table. Are there any peculiar things about this graph?

4. After making a careful study of the methods used in budding and grafting prepare some twigs to show how these methods are carried out in practice.

Chapter III · How and Why have we domesticated Animals?

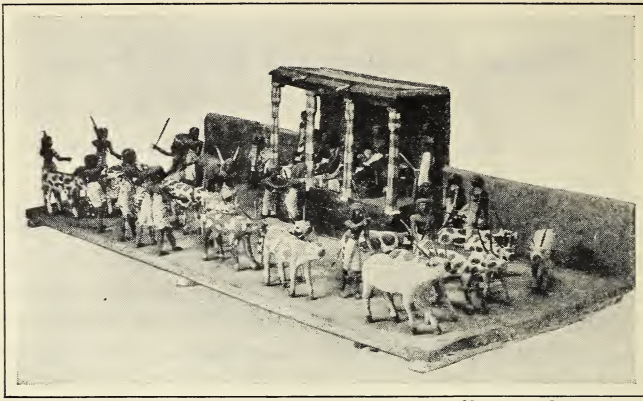
A. In What Ways are Tame Animals More Satisfactory than Wild Ones?

When you think of primitive man, as we have asked you to do rather frequently, you picture a hunter in search of food for himself and his family. When did this primitive man live? You answer promptly, "Many hundreds of thousands of years ago." In some places, yes; in other places he lives to this very day. For any people who are still in the hunting stage of civilization are "primitive." Before the coming of the white man many of the North American Indians were primarily hunters. Many tribes in Australia, Africa, and South America, and some tribes of Eskimos are hunters today — hunters and nothing else. They are primitive peoples.

But let us take a closer look at the hunters in Europe some hundreds of thousands of years ago. With the passing of the last great ice age Europe became warmer. Forests began once more to spread over Europe. First came the pine forests, and later the oaks and other deciduous trees. This increase in the number of trees diminished the areas covered by grass and thus affected the grazing grounds of the wild cattle and other grass-eating animals. Thus gradually these hoofed animals, depending upon grass for their food, were crowded into certain limited areas in what are now southern Russia and the plains of Hungary. Our primitive hunters naturally followed their food supply, living upon the grasslands in these sections and killing the animals they needed.

Primitive man followed wild cattle and protected them

But these men took care not to kill all the animals. Not only that, but they began to protect them from wolves,



Metropolitan Museum of Art

FIG. 25. Man's Control over Cattle had its Beginnings far back in Ancient History

Here the artist has reproduced a scene from ancient Egypt

saber-toothed tigers, and other enemies, realizing that in so doing they were merely making their own food supply more secure. As soon as primitive men learned that they could keep a herd of wild cattle where they wanted them by protecting them from other animals and by feeding them, they became herdsmen rather than hunters.

Animals were domesticated gradually

Thus wild cattle were brought gradually under control. Drawings and carvings similar to those shown in Fig. 25, found in ancient tombs, tell part of this story. Excavated implements for butter-making and various kinds of containers for milk tell other parts of it. But there is still further evidence in parallel experiences of the present day. Let us take as an example the Eskimo of northwestern Canada and Alaska.

Like the men of central Europe that we have just described, the Eskimo has been a hunter. He has had no domestic animals except the dog, and in most cases has had no permanent homes. His food has been a diet of the meat of wild animals. In fact, the very name "Eskimo"

means "eater of raw flesh." You will suspect that the climate in which he lives may have been an important cause of his primitive civilization at this late date.

Soon after the United States purchased Alaska, our government became interested in improving living conditions for the native Alaskans. Recognizing the fact that a group of people in the hunting stage of civilization never has a secure source of food, the government employed scientists to study the question of what could be done to provide these Eskimos with a domestic animal upon which they could depend for food and perhaps for other things as well. The animal must be adapted to live in the climate of Alaska, upon the food at hand, and it must be able to reproduce its kind there. In addition it must be an animal that was already domesticated or one that could be domesticated easily.

The Eskimos in Alaska have progressed from the hunting to the herding stage in a few generations through the domestication of reindeer

The reindeer of Siberia and northern Europe looked like a possibility. It is an animal related to our own deer, elk, and caribou. Its milk is good and its flesh tender. It can endure severe cold. This domesticated animal was accordingly introduced into Alaska in 1891, to the number of 1200. Along with the reindeer came a band of Siberian herdsmen to teach the Eskimos how to care for these new animals. Forty years later there were more than 700,000 domesticated reindeer in Alaska and Canada. A large herd is shown in Fig. 26, *B*.

The reindeer feed chiefly on lichens that live on the ground through the winter. These lichens, illustrated in Fig. 26, *A*, are commonly called reindeer moss. The reindeer paw them out from under the snow. Thus it is possible to use for pasture much land which has little value for any other purpose. Indeed both lichens and reindeer flourish within a thousand miles of the north pole, perhaps even nearer.

Thus in a single generation the Eskimos have progressed

A. M. N. H.

Fig. 26. The Reindeer and his Chief Food

A, the chief food of the reindeer is reindeer moss, a lichen which can endure the cold of the Alaskan winter. *B*, the reindeer, a domesticated animal, has helped the Alaskan Eskimo to become a herdsman rather than a huntsman

in their civilization from the stage of huntsmen to that of herdsmen. The reindeer has made this progress possible.

Now experiments in crossbreeding the domesticated reindeer with the stronger and larger, but less easily managed, native caribou are being conducted at a government station near Fairbanks. Hybrids thus produced may be even more satisfactory than the reindeer; for, as we said in the last chapter, the laws of heredity in crossbreeding animals are the same as those in crossbreeding plants.

Today the reindeer of Alaska supply their owners with milk, meat, and leather. Often the supply is so abundant that a considerable surplus can be exported. Have you ever eaten a reindeer steak? It is finding a place on the menus of restaurants and even on the dinner tables of private homes in the United States. If there were need for it, reindeer meat might become an important item in our food supply.

Reindeer supply milk, meat, and leather

The dog was perhaps the first of all domesticated animals, for he was man's companion as early as the New

Fig. 27. Some of our Native Dogs are closely related to the Wolves[1]

Should you know without being told that *A* is the huskie and *B* the wolf?

Stone Age. Whether man adopted the dog or whether the dog adopted man is an interesting question. There were advantages to be had on both sides. Bones gnawed by dogs perhaps ten thousand years ago are found in the refuse heaps, or "kitchen middens," of European man.

The origin of the dog is uncertain. There are dogs native to all parts of the world. The dogs in our country today are so closely related to foxes, wolves, and coyotes that they not uncommonly crossbreed with them and are thus constantly changing. It is said that Arctic explorers are often afraid to shoot into a pack of wolves lest they prove to be Eskimo "huskies." Perhaps Fig. 27 will show why. Dogs often disappear from farms in localities where wolves are plentiful, only to be seen later running with the wolves.

Ninety-one distinct breeds of dogs are recognized by the American Kennel Club. When you think of all the types that lie between the Russian wolfhound and the bull terrier, the German police dog and the toy Pekingese, you will not be surprised at that number.

These different varieties, like the plants you studied in Chapter II, have been developed deliberately for different

[1] Courtesy of New York Zoological Society.

Fig. 28. Many Different Varieties of Dogs have been developed for Different Purposes

A, whippet; *B*, Chihuahua; *C*, German police; *D*, Boston terrier; *E*, bulldog; *F*, Pekingese

purposes. Look at the types shown in Fig. 28. The whippet has been bred for speed; the collie to protect sheep; the Newfoundland as a life-saver; the poodle for tricks on the stage; the bulldog for bull-baiting, a popular sport in the Middle Ages; the Airedale for fighting; the setter

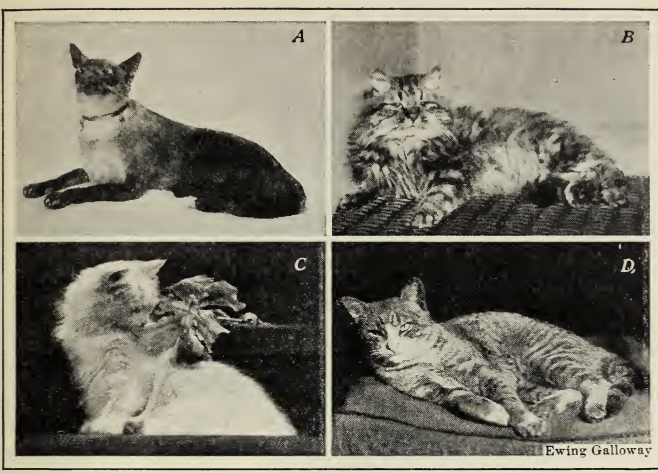


FIG. 29. Cats are Domesticated Animals

A, Siamese; *B*, Angora; *C*, Persian; *D*, common

for hunting. The Boston terrier was bred as a pet. It is small enough for a city apartment or four-room bungalow. It has a smooth coat that requires little care and leaves little hair on rugs or furniture. It is intelligent and quick and a good watchdog. The Pekingese, formerly bred to suit the fancy of the Chinese nobility, would fit into a kimono sleeve. Through application of principles of animal-breeding it seems possible to breed a dog to satisfy every fancy.

Dogs have been bred to suit man's purposes

Cats were probably first domesticated as sacred animals in connection with the early Egyptian religion, and there are still many superstitions associated with cats. They are members of the same family as the lion, tiger, and leopard and are native in all parts of the world. There are many different types. Look at Fig. 29.

The domestic cat has never really earned its salt. It has caught mice, and it has contributed a cheap imitation of

Fig. 30. Even on a Reservation such as this the Bison are not Domesticated

Do you know why?

expensive furs. Aside from that it merely eats what is given it, hunts when it has to, and multiplies rapidly. When and where necessary it is still able to take care of itself. Indeed there are more stray cats in our country today than there are cats with owners. The cat is a splendid example of an animal that is well adapted to its environment.

Cats are well adapted to civilization

B. What is a Domesticated Animal?

At what point in the process of domestication does an animal cease to be a wild animal and become a domesticated animal? At first this question seems easy. The calf in your barn is domesticated; the fawn in the meadow is wild. The puppies in the barnyard are domesticated; the young foxes in the den in the woods are wild. The ducks in the henyard are domesticated; the ducks that you see as they fly south in the fall are wild.

But suppose you take a baby raccoon or a baby lion

and tame it. It drinks milk from a bottle and later laps it from a saucer. It makes an interesting pet — until it bites you. It isn't domesticated, nor can you make it so.

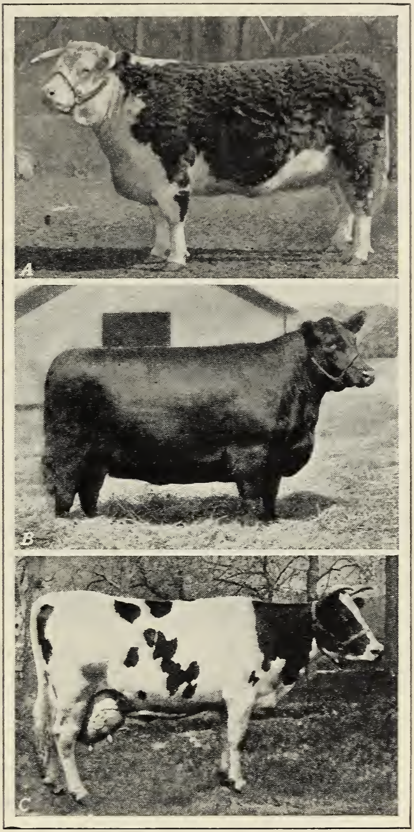


Fig. 31. Cattle are Domesticated Animals

Again, do you know why? *A*, Hereford; *B*, Angus; *C*, Holstein

You may feed gray squirrels and coax them into your parks or dooryards. They are pretty little creatures. Next year or perhaps the year after they build nests in your attic. They steal the corn from your barn. But they are not really domesticated. They do not depend upon you, although they may have taken advantage of you!

You herd bison into a reservation, as shown in Fig. 30, where they live more or less unnaturally and produce young. You may use their meat or their skins. They would die without your protection. Are they domesticated? Not yet, because they differ in no way physically from their wild ancestors. But they may be on the way to becoming domesticated. Certainly they are no longer wild.

Domestication means that the animals are unlike their wild ancestors; that they will breed in captivity; that they depend to some extent upon man; that the habitat, or home, provided for them is more or less unlike their native one; that they could not exist for long in the wild or that, if they did live, they would return to a type like their wild ancestors. As the human race has progressed in culture, the number of domesticated animals has increased.

A domesticated animal will breed in captivity. It depends upon man for food and home

Cattle are domesticated animals. To be sure, you can turn young stock out to pasture for a few weeks in summer. But your cows need more hay and grain to produce the milk they do than the best pasture will supply. Your best beef cattle are never turned out to pasture at all. Look at the cattle in Fig. 31. These are obviously not wild animals. The Hereford is much too heavy for his own good. He could not run. He could not fight. He is good only for beef. The Holstein cow produces enough milk for half a dozen calves. These specimens have been overspecialized by man in order to fit a definite need. If the Hereford were allowed to roam in a pasture, he would become thin and muscular if indeed he managed to live at all. These animals could hardly exist without the aid of man.

Domesticated animals have been specialized for a particular purpose by breeding

C. What are Some Important Domesticated Animals?

Other animals that were domesticated early in human history for their food value or for their hides include the sheep, the goat, and the pig. Animals that were domesticated as beasts of burden include the horse and the camel.

Sheep and goats appear to have been domesticated somewhere in the region of Syria or Palestine. The process was doubtless similar to the process of domesticating cattle. The shepherd is a figure of the oldest Biblical history, and

descriptions of the shearing of sheep date back to three or four thousand years before Christ.

Probably the first horse was tamed on the plains of central Asia, where the wild horse is still found today (Fig. 32, *A*). Some one of you may say at this point, "Why, there are wild horses on the plains in the United States." True, but these wild horses have been wild only a few generations. These are descendants of horses that were brought to this country by the Spaniards. Previous to the coming of the Spaniards there had been no horses on this continent for hundreds of thousands of years.

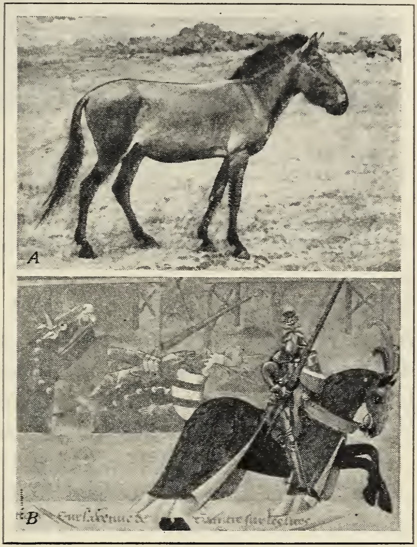


FIG. 32. *A*, Wild Horses similar to this one in a Painting by Charles R. Knight may still be found on the Plains of Ancient Asia. *B*. Horses were used throughout Ancient and Medieval Civilization

Do you think the people of the Middle Ages bred horses especially for tournaments?

You have already learned some facts about a little horse-like animal about as big as a small terrier, the eohippus, whose bones may be found in the soil of our own Southwest. This little animal is believed by scientists to be a distant ancestor of the modern horse. It lived in this country long before there were any people in America. In some manner unknown at present the descendants of the eohippus seem to have spread into other parts of the world. Tribes of semicivilized people that migrated into Asia

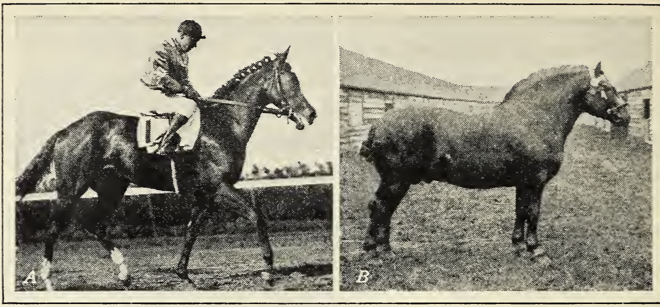


FIG. 33. Modern Horses are bred for Various Purposes and differ Accordingly

A, a race horse bred for speed; *B*, a Percheron bred for work purposes. (Courtesy of Fred Smith, secretary of Suffolk Horse Society, England)

Minor from the East about 2000 B.C. came riding upon horses, packing their possessions on the backs of others. Although the oldest fossil remains are found in America, the horse did not continue to live here. There were no horses in America during the Age of Man.

Horses were used throughout ancient and medieval civilizations. The Greeks used horses. So did the Romans, and so did the knights of the Middle Ages, as shown in Fig. 32, *B*. But the American Indian roamed the plains on foot. He had no beasts of burden.

The modern horse is intelligent, being excelled in intelligence only by the great apes and the elephant. He is large enough and strong enough to carry heavy loads; a good draft, or work, horse often weighs as much as a ton. His feet are adapted for running or walking long distances. A good horse can travel as much as a hundred miles in a day, although he could not keep up this pace for days in succession.

Modern horses have been bred for several purposes and differ accordingly. If you should see a draft horse, a racing horse, and a saddle horse side by side, you would probably

have little difficulty in telling them apart, even though you had not been told which was which. The draft horse is much the heaviest. He has short legs, a broad chest, and a thick neck. His feet are large and broad. A Percheron, an especially fine breed of draft horse that was brought here from France, is shown in Fig. 33, *B*. The racing horse is of course bred for speed. Some splendid specimens have been produced. Who is not stirred by a horse such as the one in Fig. 33, *A*?

Horses have been bred for several different purposes

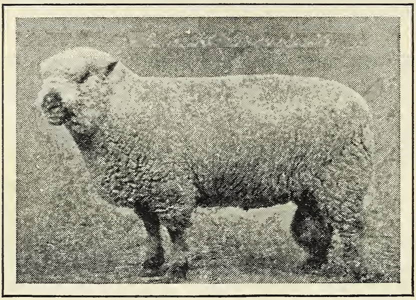
The saddle horse has come into its own in recent years in this country, owing to the increased interest in horseback riding. Many "carriage horses" and "coach horses," whose usefulness had diminished with the coming of the low-priced automobile, have been put to work again as saddle horses.

A superior herd of milk cattle is probably made up of Jerseys or Holsteins, although Guernseys and Ayrshires are also good breeds of milk cattle. A cow produces her first calf when she is between two and three years old. Normally she gives birth to one calf a year, though occasionally to twins. The calf uses its mother's milk for about six weeks. Ordinarily even during this time the calf does not use all the milk, and what is left is used by human beings. But after six weeks all the cow's milk may be used to meet human needs. The cow may give milk for from six to eight months or longer, as much as twenty quarts a day when the calf is first taken away from her. One registered Jersey gave 10,627 pounds of milk during one year, while a registered Holstein gave 13,986 pounds of milk during the same period. The Jersey, however, gave 521 pounds of butter fat, while the Holstein gave only 486 pounds. Profit on these two cows for one year exceeded $200 each. These were not record-breakers, but simply good cows in a good herd. Good cows are those producing over 300 pounds

Cattle may be bred for milk, cream, beef, or other purposes

of butter in a year. A Shorthorn holds the record in butter production for all breeds. This record cow produced in one year 32,522 pounds of milk (about 8000 gallons), and this milk contained 1614 pounds of butter.

Two types of cattle raised exclusively for beef are the Aberdeen Angus and the Hereford. These breeds give comparatively little milk, but make splendid meat. An Aberdeen Angus calf may weigh as much as 1000 pounds by the time it is a year old. It is fed on grain and hay until it is fat enough to be killed.



Geo. McKerron & Sons

Fig. 34. This Ram was bred "to Order"

How do you think it was done?

For sheep-raising, the Shropshire is our most popular breed for meat production. As were many kinds of dogs, horses, and cattle, this ideal Shropshire sheep was planned first and then bred to fit the plan. The principles governing each case are the same as those described in Chapter II. The American public demanded tender meat without strong flavor. The butchers wanted plenty of meat on the best cuts. The climate of this country demanded an animal born in the spring and ready for market in the fall.

American sheep were bred to meet the American taste

Early in this century American breeders visited England and Scotland, for in these countries breeding of superior sheep has been carried on for centuries. But superior sheep for England and Scotland were not necessarily superior sheep for America. The British Isles have a mild winter season, for instance, and the British public likes strong mutton. But certain carefully selected animals were pur-

chased and brought home. One ewe, mated with an American ram, produced several exceptional offspring, close to the ideal that had been set. A grandson, named Senator Thickset (Fig. 34), received four first prizes at the International Livestock Show in 1929. He was the father of the first-prize pens of both ram lambs and ewe lambs. He took similar honors in 1931 and 1932, while his sons and daughters are still winning blue ribbons.

One more farm animal is sufficiently different and sufficiently important to deserve our brief attention. We refer to the hen, whose ancestors came from the bamboo jungles of India or possibly Malaysia.

Hens have been bred for flesh, feathers, and eggs

The modern fowl has been bred for its flesh, its eggs, and its feathers, in the order of their importance. Some of the results of domestication and continued careful breeding may be seen by comparing the red jungle fowl in Fig. 35, *A*, with the White Wyandotte in Fig. 35, *C*. The wild jungle fowl is a poor source of food when compared with the White Wyandotte.

One especially important man-produced improvement among the characteristics of the modern fowl is in the time at which pullets begin to lay. Some of the best now lay their first eggs when only five or six months old. This means that, since the chick was hatched in the spring, the hen will be laying during the winter months, when eggs are less plentiful and therefore more expensive. It also means a shorter period before the hen begins to pay for herself.

Some of the most popular breeds of hens in the United States are the Plymouth Rock, the Rhode Island Red, the White Wyandotte, and the White Leghorn. Some of these breeds are shown in Fig. 35. Whiteness as inherited in some varieties is a dominant Mendelian characteristic, while in others it is recessive. Rose or double combs, as opposed to single combs, are always dominant. Early maturity appears also to be a dominant characteristic.

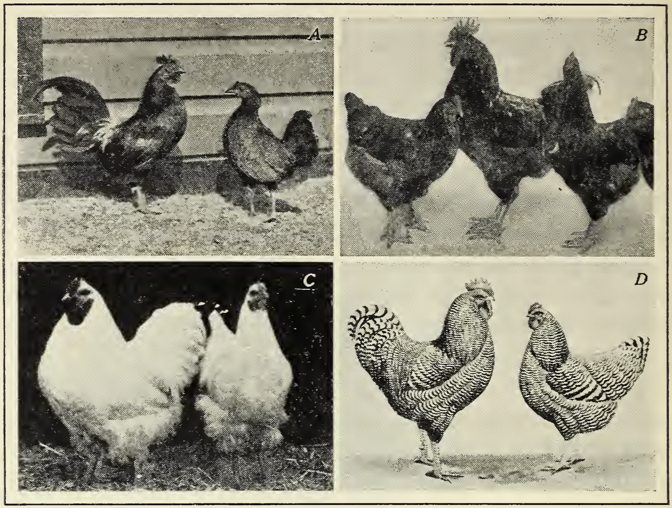
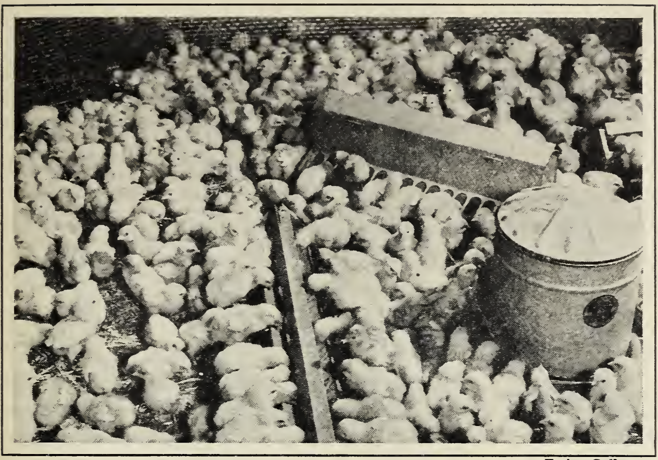


Fig. 35. Many of our Domestic Fowls are the Result of Scientific Breeding

A, red jungle fowl; *B*, Rhode Island Red; *C*, White Wyandotte; *D*, Plymouth Rock. What differences can you find in the various species shown?

Let us consider a flock of Rhode Island Red hens. All of course are red. A White Leghorn rooster is added to the flock. Next season when the chickens hatch, every single one is white! But you must not expect that these white chickens when mature will themselves produce white chicks. If a rooster from this hatch is kept with the hens from this same hatch, you will have some red chicks again next season, this time in the ratio of three white ones to one red one. But if these second-generation red ones are now separated and kept together, they will never produce a single white chick! One third of the white ones will produce only white chicks, but the descendants of the other white ones will again appear in the ratio of one red to three whites. These results, as you will recognize, are exactly what you would expect according to Mendel's first law. White in this case is a dominant characteristic, while red is recessive.



Ewing Galloway

FIG. 36. The Raising of Poultry today depends upon Scientific Principles

What advantages do you think an incubator has over a hen? Are there any disadvantages?

On the larger poultry farms eggs are hatched almost exclusively in incubators (Fig. 36). This saves three weeks' time during which a hen might be laying, and it makes possible a hatch of two or three hundred or more eggs at one time. Incubators must be tended carefully in order to keep a free movement of air and in order to keep the proper temperature. This temperature must be that of the hen's body, which is about 120° F., and it must be kept even during the entire three weeks of incubation.

D. What is the Future of Fur Farming?

Although man has used the fur of wild animals almost as long as he has depended on them for food, he has not attempted until recently to raise fur-bearing animals in captivity.

Scores of animals have been used for their fur. The list includes the beaver, muskrat, seal, raccoon, fox, skunk,

squirrel, marmot, and rabbit. Some of these are shown in Fig. 37. How many have you seen as wild animals?

Fur is the hairy outer covering of an animal, which has grown thick and soft and protects it against the cold of winter. As a consequence the best furs are obtained from animals that live in the cooler regions of the world, and then only during the winter months. Warm weather affects the hair follicles, or glands, of the skin so that they cease all activity. Dull lifeless coats are shed. But approach of winter again causes renewed activity.

Animals have been hunted for their fur

Hunters have always obtained furs for themselves and their families without seeming to lessen the supply. But as soon as trappers and traders began to get skins in large numbers to sell in the open market, the danger of extinction of some of our wild animals became great. Beavers and seals appeared to be doomed. Even muskrats were growing fewer. The result was obvious: enterprising trappers and traders saw possibilities in fur farming. Rabbit farms, skunk farms, and raccoon farms were started. Fox farms followed soon after, while recent accounts of a chinchilla farm show that even some of the most precious of furs may be raised under controlled conditions.

Fox farming is an important industry

Conditions on a silver-fox farm illustrate the methods developed in fur farming. The silver fox is believed to be a freak offspring, or mutant, of the common red fox, varying from it only in color. Its soft short underfur is black, and the long guard hairs are black except for a white ring a short distance from the tip. It is these white rings that give the fur the appearance of frosted silver. In any family of wild red foxes there may be an occasional black one and a still more occasional silver one. The best silver foxes have been developed by breeding blacks together until only blacks or silvers remain. But since black is dominant, a person buying foxes for breeding purposes must be sure that he purchases them from a

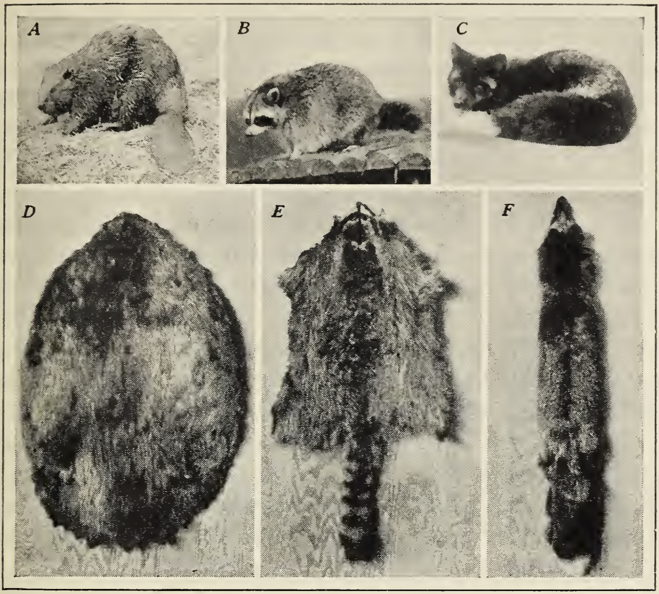


FIG. 37. Many Animals are valued for their Fur

The animal is shown above, the fur below. *A* and *D*, beaver; *B* and *E*, raccoon; *C* and *F*, silver fox[1]

reliable ranchman; if he does not, as much as a quarter of his stock may prove to be red! Do you see why?

Many of the silver-fox farms today are located on Prince Edward Island and in Michigan. There are now more than five hundred such farms in the United States. In order to raise foxes successfully a man must know about the history and habits of foxes and must buy the best animals he can find.

There are many species of foxes, scattered throughout the world from the Arctic to the tropics. There are probably more varieties and color differences among foxes than among any other species of fur-bearing animal.

[1] Photographs *A* and *B* are used by courtesy of the New York Zoological Society; *C*, from the Department of the Interior, Canada.

Foxes mate in midwinter. Their young are born in March or April, and there may be from one to nine in a litter, or brood. The young are blind and almost furless for the first three weeks of their lives. The mother remains in the den with them during this time. She allows the father to bring her food, but will not let him enter the den. Nor will she let anyone else come near. It is an anxious time for the ranchman. When at last the mother appears safe and sound outside the den with her little ones, he rejoices. By the time the whelps, as the little foxes are called, are six or seven weeks old they begin to eat solid food and grow rapidly. Both father and mother keep close watch over them, helping them to secure food and disciplining them whenever necessary.

You may ask if the silver fox has become a domesticated animal. Well, it has to some extent. At any rate, almost all the silver-fox skins on the market today come from animals that have never known a day in the wild.

Man has domesticated animals to supply definite needs. He has bred them to satisfy these needs, observing the laws of heredity in the case of animals as closely as in the case of plants. Modern horses, dogs, cattle, hens, and sheep show the results of careful breeding. Foxes and other fur-bearing animals are raised successfully and are becoming domesticated because man needs them.

Can You Answer these Questions?

1. How did the domestication of animals make it possible for man to establish more-permanent homes?

2. What is a domestic animal?

3. Do the Mendelian laws apply to the heredity of animals? What evidences do you have to support your answer?

4. How does the modern hen compare with the wild jungle fowl in the characteristics which to us seem desirable? How does she compare in ability to live without the protection of man?

5. Can you explain why red foxes might appear in a litter from a pair of silver foxes of unknown pedigree?

6. What characteristics of a draft horse and of a race horse make each suited particularly to its type of work?

7. What is meant by the statement in regard to sheep that "the ideal Shropshire sheep was planned first and bred afterwards"?

Questions for Discussion

1. Could domesticated animals live if they were suddenly deprived of man's care and protection? Can you think of any that might go back to their wild state?

2. The statement is made that animals are bred for different characteristics, such as speed, weight, size, or color. How do you think this breeding is done?

3. What do you think about the question as to whether the dog first attached itself to man or man to the dog?

4. Why were most American Indians hunters rather than farmers? What domestic animals did the Indians have when the first white man came to America?

5. We often say that this is a machine civilization. Is this true of farm life?

6. Do you think that such animals as the fox or the raccoon flourish best in their wild state or in their domesticated state?

7. Do you think that it is correct to say that an animal is or is not intelligent? What evidence could you present to support your case?

Here are Some Things You May Want to Do

1. Many good stories have been written about wild and semi-wild animal life. If you have not already done so, you might like to read Jack London's *Call of the Wild,* Ernest Thompson Seton's *Lives of the Hunted,* or some of Albert Payson Terhune's dog stories.

2. We speak of the value of fur which is now produced by domesticated fur-bearing animals. See if you can find the types of animals most often used for this purpose, how they are domesticated, and how the value of their fur compares with that of the animal trapped in its wild state.

3. Make a study of the heredity of some prize cow, horse, hen, or dog. If you wish to make a more general study, look up the history of some special type, such as Shorthorn cattle or the Ancon sheep. See how far back you can trace its ancestry. Perhaps pictures or diagrams would help to make your story clearer. If you have a kennel club or a cattle-breeder's association in your locality, they can help you.

4. Make a special study of the red jungle fowl of India, using Beebe's *Pheasants*. There are other possibilities along the same line. Where, for example, did the domestic dog, goose, or turkey have its origin?

5. Imagine that you had been given money to buy just the type of dog you wanted. Which one should you select, and why? You might wish to prepare a good "sales talk" on your favorite dog.

6. Because of their value many fur-dealers today put fancy names on furs that commonly would not be purchased. For example, Hudson seal is dyed muskrat. Go through your local newspaper and see how many fur names you can find that are not familiar. Then try to find out what animals are used for them.

7. If you or any of your friends have a new litter of kittens or puppies at home, study them to find individual characteristics which have been inherited from their father and their mother. Consider such questions as Do some resemble one parent, and others resemble the other parent? Are any of them entirely unlike either parent? See what other interesting things you can find out about them.

Chapter IV · What Conditions give the Most Efficient Growth of Crops?

A. What General Conditions are Necessary for the Growth of Plants?

What, in the eyes of a gardener, makes up good soil? Where is a good place to plant your garden? What things are needed by all green plants?

Plants need water and air

It would not be very hard for you to prove that plants need both water and air. Doubtless you have done so in your earlier science work. You will remember that water is needed in order that the roots of a plant may take in dissolved mineral food from the soil and in order that materials may be carried to all parts of the plant. But the plant needs air also in order that the food-making and food-using processes may go on. The leaves of a plant use both carbon dioxide from the air and water from the soil in the manufacture of carbohydrates. The plant needs oxygen from the air so that it may use the food which has been made. The oxygen combines with the chemical elements in the foods to produce the energy needed for living. As a result of these chemical changes the foods are reduced to simple substances.

Plants need sunshine

In addition to air and water you know that plants need sunlight. You have observed the leaves on plants in sunny windows. You have noticed the positions of individual leaves on a tree. And you may have seen stems that grew far beyond their natural length in an attempt to get into the sunlight. You may have read, too, of jungle vines and other plants that begin growth upon the forest roof. And you know that plants develop rapidly in the long daylight hours of summer in Canada and Alaska. These and similar observations should confirm your opinion that plants need light.

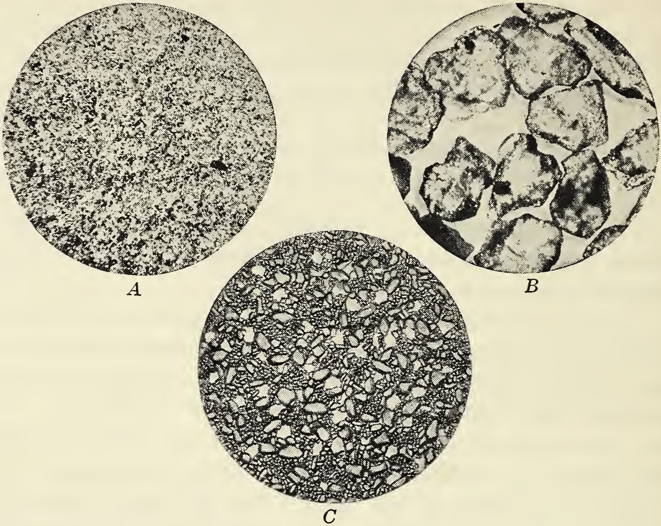


Fig. 38. Different Soils differ in Many Respects

What differences can you find in *A*, clay; *B*, sand; *C*, loam?

The fourth need for the successful growth of plants is summarized in the all-inclusive expression "good soil."

Plants need good soil

This is a matter partly of the physical structure of the soil and partly of its chemical composition. It is with the question of soil that this chapter is chiefly concerned. What is the character of good soil?

On the basis of their physical structure soils may be described as sand, clay, and loam. Can you see the differences in the soil samples in Fig. 38? On the basis of chemical composition they are described as acid or alkaline and as rich or lacking in sulfates, phosphates, lime, nitrates, potash, or other compounds important to the growth of plants.

A sandy soil is coarse, open, and usually dry, because sand does not hold water to any great extent. Much of the water in soil is held clinging upon the surfaces of bits

of soil. In sandy soil there is a relatively small amount of surface as compared with a finer soil. You may see why this is so by examining Fig. 38, *B*. Consequently, sandy soil holds less moisture. A sandy soil is warmer than other soils early in the spring. Since sandy soil contains less water, an hour of sunshine will warm it more than the same amount of sunshine will warm a wet soil.

There are many kinds of soil

Clay is composed of very fine, compact particles, or pieces. Surrounding each small particle is a film of water; and since there are so many of these particles, a soil that is mostly clay is likely to be a wet soil. Sometimes the particles are so compact that plant roots can hardly penetrate the spaces between them (Fig. 38, *A*). But usually a clay soil contains more dissolved mineral substances than does sand. It also stays warm later in the fall, since it contains more water and loses heat more slowly. Water, you may know, is slow to warm up in comparison with air or rocks, but once warm it takes a long time to cool. In scientific terms we say that the specific heat of water is higher than the specific heat of soil.

Intermediate between sand and clay is silt. None of these terms tell anything about the chemical composition of soil. They refer only to the size of the particles of which the soil is composed. Particles of soil are called sand if they range in size between $\frac{1}{25}$ inch and $\frac{1}{500}$ inch. Particles larger than sand are called gravel. Silt ranges in size from $\frac{1}{500}$ inch to $\frac{1}{5000}$ inch. Extremely small particles, less than $\frac{1}{5000}$ inch in diameter, are called clay.

Humus is the name given to remains from partly decayed plant or animal matter in the soil. A soil that is rich in humus is likely to be light and porous; it is not closely packed together. It also contains the minerals needed by plants, especially sulfates, phosphates, and nitrates, which came from the decayed plants or animals. If not well supplied with air, however, a soil rich in humus has a tendency to become acid. Acids are formed as the

Fig. 39. Good Soil is a Mixture of Many Things

materials that made up the protoplasm (living matter in the cells) of the plants and animals are broken down into simple substances. One of the acids is carbonic acid. This acid (H_2CO_3) is a product of the combination of carbon dioxide (CO_2) and water (H_2O). The carbon dioxide is given off in the process of decay, or oxidation, of protoplasm.

Loam is soil composed of a mixture of sand, silt, clay, and humus. Loam is good soil for most cultivated crops because it is open enough to admit the needed air for plant roots. Besides, it holds moisture, but not too much; and it contains minerals needed as food by growing plants. Loams are sometimes divided into two classes, sandy loams and clay loams. Can you guess the difference? Do you think there would be any definite dividing line between the two classes?

Good soil should also contain earthworms and different kinds of bacteria, plants so small that they can be seen only through a microscope. Fig. 39 is a photograph made from a sample of good soil. Notice that it is a mixture of sand, silt, and clay. It must contain certain chemicals, each in the proper amount. Of these you will learn more later in the chapter.

Underwood & Underwood

Fig. 40. **The Successful Cultivation of Rice requires Heat and Moisture**

Do you think the environment shown here is good for rice?

But, you may say, there are all sorts and conditions of soils in the world, and still plants grow nearly everywhere. How is this? Can it be that different plants need different conditions in which to grow? Do some need more sunlight than others? Do some need more moisture, more warmth, or more dissolved minerals?

Different plants need different kinds of soil

If you stop to think about a few of the plants with which you are familiar, — rice, cotton, corn, potatoes, citrus fruits, cranberries, oak trees, coconuts, or reindeer moss, — you realize that certain factors are necessary for growth in any of them but that other factors may vary considerably both as to kind and amount. Rice, for instance, requires considerable heat and abundant moisture, as you can see from Fig. 40. Most varieties of corn require light, sandy, alka-

line soil. Cotton requires more warmth and a longer season of growth than potatoes; citrus fruits require more warmth than wheat. Cranberries grow only in acid bogs. They flourish where corn and oats would not grow.

The environment in which a plant grows is often spoken of as its habitat. We recognize such habitats as those of the jungle, the desert, the arctic tundra, the seashore, and the open sea, — to mention only a few. Upon a single farm in the United States we may find forest land, swamps, peat bogs, pasture, sandy upland, and moist meadows. Upon each kind of land we find different plants.

A cultivated plant, in general, needs the same kind of habitat as its wild relatives or ancestors. Therefore plants should be studied in their native habitats. Because many people fail to do this, they are unsuccessful in their attempts at transplanting wild flowers or shade trees. Have you ever tried to transplant a fern from a cool damp spot to a sunny garden? Careful study of native habitats made possible the successful rubber plantations and the cultivated blueberry, to mention only two examples.

The Spaniards who settled Mexico in the sixteenth and seventeenth centuries tried in vain to grow in the new country the crops with which they were familiar in Spain. It was not until they began raising native Indian crops that they had any degree of success. On the other hand, the Pilgrim Fathers in Massachusetts took advice from the friendly Indians. They were saved from starvation by their success with corn, squashes, pumpkins, and potatoes, all of which were native crops.

Experience has shown that some plants require an acid condition of the soil, while others require a soil that is alkaline. Blueberries, arbutus, cranberries, and wintergreen grow best in acid soils. Experiments by experts in agriculture have confirmed earlier observations to this effect. If you wish to have clumps of mountain laurel or rhododendrons about your house, you must provide them

also with acid soil. This may be done by adding small quantities of certain acid salts to the soil or by keeping a supply of leaf mold around them.

Grass grows best upon a lawn that is slightly acid. On the other hand, almost all garden vegetables require an alkaline soil. Calcium carbonate ($CaCO_3$), commonly called lime by the gardener, acts as an alkali in the soil, in that it will act chemically with acids and neutralize their effects. If you add lime to your lawn, you are encouraging a fine crop of weeds, since weeds are better adapted than grass to the alkaline condition.

Garden vegetables need an alkaline soil

B. How should Land be Cultivated?

Since the very beginnings of agriculture man has used the hoe, the plow, the spade, and the scythe or sickle. Probably his first plow was only a stick, forked so that it would cut a better furrow. Even the men of the New Stone Age knew that plowing their land improved it in several ways.

Plowing destroys many weeds by uprooting them, so that the land is left clear for planting. It lets in air and loosens the soil, so that roots may penetrate the soil more easily. It keeps water in the soil by preventing rapid evaporation, as may be seen from the following experiments. Can you see evidence of these effects in Fig. 42? Hoeing serves the same purpose. You must hoe the garden to save moisture as well as to cut the weeds.

Plowing destroys weeds, lets air into soil, and prevents rapid evaporation

1. Get two flowerpots of the same size and fill them with loose, well-powdered soil. In one pot make no attempt to pack the earth tightly, but level it off evenly at the top. In the second pot push the soil down just as hard as you can. Pack it down until you have come as near as possible to conditions in an unplowed field. Now set both pots in

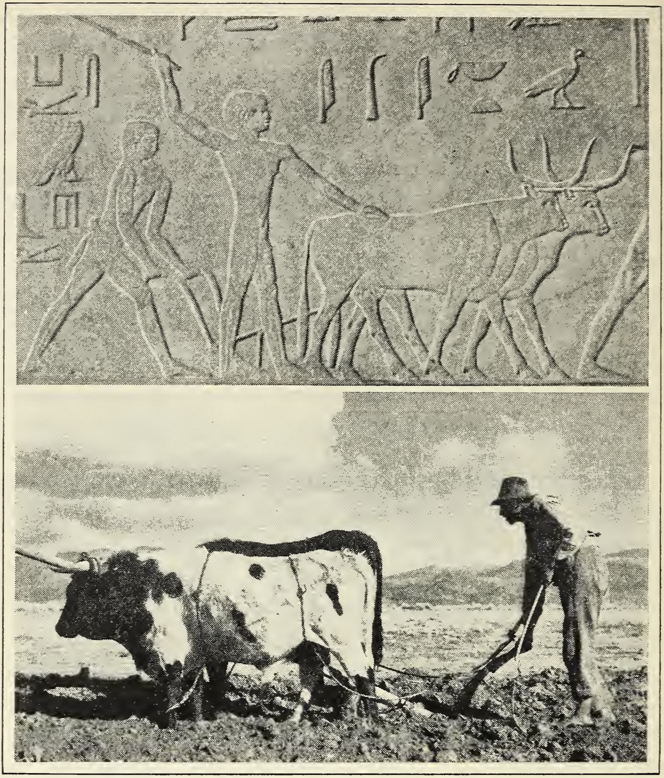


FIG. 41. Some of our Processes in Agriculture have a Primitive Origin

Above, an agricultural scene about 3000 B.C., as carved on the walls of an Egyptian nobleman's tomb. Below, a farmer of today in a primitive part of the world. Are there any differences?

a pan of water. In which pot does the top of the soil become moist sooner? Which absorbs water more rapidly? Which will lose water more rapidly by evaporation?

2. Take two lumps of sugar. Place one on top of the other in a saucer of colored water. Watch the water as it rises. How do you account for the effect just as the liquid reaches the top of the bottom lump?

Developments in plowing have been largely the result of development of better machines for doing the work. Contrast Fig. 41 with Fig. 42.

When man was young upon the earth and there were many more square miles of possible farming lands than there were men to cultivate them, the problems of keeping soil in good condition were not serious. If the land "ran out," the early farmer had simply to move on to other lands that were better. But the time came in many of the more desirable parts of the world when men became more numerous than the good farms. Then these lands became valuable. They must be kept in good condition for raising crops each year or at least nearly every year.

Fig. 42. Plowing is Important for several reasons

Contrast this picture with Fig. 41

Agriculture and the early agricultural civilizations, such as that of the ancient Babylonians and Assyrians, began upon the flood plains of the world's large rivers. Each spring the Tigris-Euphrates overflowed its banks and spread upon the fields a layer of fine rich soil brought down from the mountains to the north. This soil contained mineral substances dissolved from rocks, and it contained humus. Each year the farmers in the river valley had fine rich soil in which to grow their crops. Similar conditions prevailed in Egypt. But as the

Most land must be fertilized

population of the world increased and it became necessary to farm other lands farther back from the flood plains, something had to be done about fertilizing them. Man had to add to his "gifts from the gods."

What becomes of the mineral substances that play such an important part in making rich soil? Why do they need to be renewed? Plants use them in growing, or building new cells. Every bit of living protoplasm contains nitrogen, and usually sulfur, potassium, phosphorus, and other elements. There may be as many as sixteen different chemical elements in the cells of a living body. Except for carbon from the air all these are taken from the soil, either directly in the case of plants or indirectly in the case of animals. In a forest or a field where plants grow and die, where animals may eat the plants but in time die upon the same soil, these substances, although taken from the soil, are later returned to it. The uncultivated field or forest is like a balanced terrarium except that rain water flowing over the soil carries some of the minerals away in solution. Except for changes caused by running water the mineral content would remain the same.

The removal of crops from the land leaves the soil poorer

By way of contrast take a field of wheat. It grows upon the soil and takes minerals from it, for minerals are needed in making living tissue. It is harvested and sold. Consequently the land has lost part of its mineral wealth. This process, even upon the richest lands, cannot go on indefinitely if man expects the best of crops. When man interferes with nature in this way, he must do something to make good the loss.

The first type of fertilizing was in the use of manure from the farm animals. Such matter has its origin in plants; therefore it contains the chemical elements necessary for plant growth. Later, weeds were plowed in so as to provide humus, or "green manure," and the compost heap was used. This consists of both plant and animal refuse piled up

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FIG. 43. Large Deposits of Saltpeter, or Sodium Nitrate, are found in Chile

If you will look at a rainfall map of South America, you will find that these deposits are located in a region where there is almost no rain

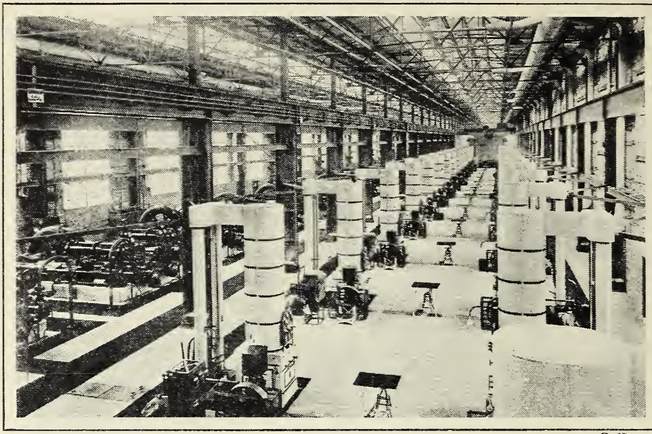
and allowed to decay. When partially decayed it is spread upon the fields. Compost contributes to the land the minerals that had been taken from it by plants as they grew.

Farmers early learned that lime may be added to the soil to get rid of an acid condition. An acid common in the soil results from the decay of humus where there is insufficient air. This acid acts with the alkali from lime to form a salt which is inactive in the soil. Such a process is this:

$$2\ HNO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + H_2CO_3$$

Nitric acid and calcium carbonate (lime) react to produce calcium nitrate (a salt) and carbonic acid. By a further step the carbonic acid is decomposed, or broken up, into carbon dioxide and water. Lime is contained in ground bones or bone ash, clamshells, or crushed limestone.

No other advances in the method of fertilizing were made



Galloway

FIG. 44. Nitrates are now made from the Air in Plants such as this One

until, in the last century, guano beds were discovered on islands off the dry western coast of South America. These guano beds consist largely of the droppings of birds that live along the rocky cliffs. Guano spread upon the fields increases the nitrogen, potassium, and phosphorus content of the soil.

Nitrogen compounds are manufactured from nitrogen of the air

Chile saltpeter, or sodium nitrate ($NaNO_3$), found extensively in Chile (see Fig. 43) has been exported in large quantities from that country. This deposit in Chile is the only important deposit of nitrates known in the world, and before 1915 most of the nitrates used in the world came from this source. The supply was rapidly diminishing, and in the minds of some there was grave fear for the future of civilization. During the World War a chemical process was developed for making nitrogen compounds out of nitrogen from the air. Now there is an abundance of nitrogen compounds for every possible need. Fig. 44 shows the interior of a modern plant. See if you can find out anything about the process.

Ewing Galloway

FIG. 45. Southern Germany is an Important Source of Potash

The picture shows the interior of a potash mine

In addition to nitrates plants need phosphates. These are supplied artificially, chiefly in the form of bone meal and phosphate rock. Bone meal, as its name suggests, consists of the bones of animals. It is a by-product from slaughter-houses. Phosphate rocks are found in Florida, Tennessee, and a few other places. They are natural compounds containing phosphorus.

Plants need potassium compounds also. Potassium compounds are part of the mineral matter left from burning and decay. Your great-grandmothers may have obtained potash from wood ashes, for use in making soap. Today potassium compounds are obtained from natural potash deposits (see Fig. 45), the most important of which are found in southern Germany.

From this description you may note that plants need a number of elements for growth. About sixteen chemical elements are used by plants. Some of them are present in

the soil in sufficient quantities so that there is little need to worry about them at present. Other elements must be renewed in land that is constantly under cultivation.

Plants use simple chemical compounds

The elements taken from the soil must be present in simple compounds. To take a very simple case: when a plant makes sugar, it must use carbon dioxide and water. The carbon, oxygen, and hydrogen as uncombined elements would be of no value in the food-making process. Likewise when a plant makes protoplasm, it needs nitrates, phosphates, sulfates, and carbonates. But it cannot use nitrogen, phosphorus, or sulfur as simple elements.

C. What are Reasons for Rotating Crops?

The poet Virgil, two thousand years ago, advised the Roman farmers to

> learn the peculiarities of your soil and climate — Either let the land lie fallow every other year or else let spelt follow pulse, vetches, or lupine. Repetition of one crop exhausts the ground; rotation will lighten the strain, only the exhausted soil must be copiously dressed with manure or ashes.

Legumes enrich the nitrogen content of the soil

Farmers no longer follow the advice of Virgil with respect to fallowing. Crop rotation is, however, recognized today as important in maintaining soil fertility. The crops included in a plan of rotation are different in different places. A typical three-year plan of rotation for the corn belt is corn, wheat, and clover. In the cotton belt it may be cotton, corn, and clover. A four-year rotation common in New England is (1) corn, (2) oats, (3) clover, and (4) timothy. Such a crop-rotation plan is shown in Fig. 46. In each case clover or some other legume is used because legumes store nitrogen and thus enrich the soil.

It was not until about fifty years ago that the chemist Berthelot and others suggested a reason why a grain crop

FIG. 46. The Modern Farmer rotates his Crops

The plan shown here is only one of many. Do you know of any others? Of what benefit is crop rotation?

should follow a crop of legumes, such as clover, peas, beans, vetch, or alfalfa. It had been suspected and later proved that legumes enrich the nitrogen content of the soil while other crops use up the nitrogen.

Two German scientists performed the following interesting experiment. They planted clover seeds in pure sand that had been baked so as to kill bacteria. The clover grew rather poorly, and under these conditions it did not add to the nitrogen content of the soil. Then the scientists ran some water through a pot of garden soil. A few drops of this water were added to fresh sand, in which they planted

United States Department of Agriculture

FIG. 47. Nitrogen-Fixing Bacteria live upon the Roots of Many Legumes, such as Clover, and convert the Nitrogen and Oxygen of the Air into Nitrates

The picture shows the nodules upon roots of soy bean

more clover seeds. This time the clover grew better, and the nitrogen content of the soil was increased. This may have seemed strange indeed, but there is a good scientific reason why water that had flowed through rich soil and then had been poured on the soil that had been baked caused clover to grow more luxuriantly in the baked soil.

After further experiments and after observations of the roots of the clover the following explanation was made:

Certain bacteria can convert nitrogen and oxygen into nitrates

There are certain bacteria in the soil — introduced in the above experiment in the garden water — that are able to convert nitrogen and oxygen of the air into nitrates. These "nitrogen-fixing" bacteria live in nodules, or bunches, upon the roots of the legumes. You may see the nodules if you look for them (Fig. 47). The bacteria within them may be seen with a good microscope. The bacteria obtain part of their food from their hosts (the legumes), but take

nitrogen from the air. The host plant in turn uses the products built up by the bacteria. Legumes may be cut for fodder or may be plowed under for green manure.

Experiments show that different crops have different needs. Certain crops require more phosphates, others more nitrates, and still others more potash. Wheat draws heavily upon the store of nitrates. Clover draws more heavily upon the potash and phosphate.

Much more knowledge is needed about crop rotation. A recent report from an Eastern state gives some interesting figures on the yield when certain crops were followed by certain other crops. Potatoes, for instance, yielded 324 bushels per acre when following cabbage, and 466 bushels per acre when following squash. Rutabagas after cabbage yielded 900 bushels per acre, while rutabagas after rutabagas yielded only 417 bushels per acre, other conditions being equal.

Another value of crop rotation is the economical use of farm labor. Some kinds of crops demand attention as soon as the frost is gone in spring. Others demand most care during the summer months, while still others require most work in harvesting. If the farmer can plan his work and that of his men and machines so that some comes at one time and some at another rather than all at once, he has taken one more step toward effective control of his environment.

D. How are Farm Lands protected from Erosion?

As farmers have become limited in their choice of lands and as it has become increasingly necessary for them to use what they have, problems of drainage and irrigation have grown in importance. Can swamp land be farmed? Can semidesert land?

The farmer must first of all consider the crops that are adapted to his particular kind of land. If he has a warm, wet meadow south of the frost line, he may be able to raise

Loibelmann Syndicate

Fig. 48. Certain Soils from Dry Wind-Blown Land drift like the Sand of the Seashore

The picture shows topsoil from a Mid-Western farm during a severe period of drought

rice. For such a crop, water is needed in abundance. If he lives upon dry wind-blown land, one of the new sorghums may be just the thing. A farmer upon such land may be especially successful with grass and grains. His next-door neighbor who attempts vegetables may find that the topsoil of his field has been blown away (Fig. 48). Vegetables should not be grown on such dry soil.

But having chosen crops as nearly suited to his land as he can find and having taken advantage of expert advice that may be had from state-college or agricultural-experiment stations, the farmer may still find it necessary either to drain the land or to irrigate it. Large areas of semidesert lands in our own West have been watered artificially by means of ditches (Fig. 49). Other areas are lined and crosslined by ditches, as in Fig. 50, dug for the purpose of draining off surplus water. But the problems of

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Fig. 49. Proper Methods of Irrigation have changed Areas of Land once Arid into Rich Farm Country

Fig. 50. Drainage Ditches are sometimes used on Land which without them would be Unfit for Agricultural Use

too much or too little water upon the land are as yet far from being solved. Is there waste land in your community?

Not long ago we passed a sandy hillside near a state road. A forest of white pines that had covered this area had been cut some seven years before. Now down the side of the hill gaped two long gullies, one of them about fifteen feet deep and more than thirty feet wide, the other not quite so large. At the foot of the hill and spreading well out over the cement of the state road was a V-shaped ridge of sand. "A few more rains," we remarked, "and that hill will bury the road." "Bad planning, cutting those trees," returned our companion. Yes, trees would have held that soil. Grass would have held it. But bare land cannot remain upon a hillside against the force of running water. Erosion will necessarily result.

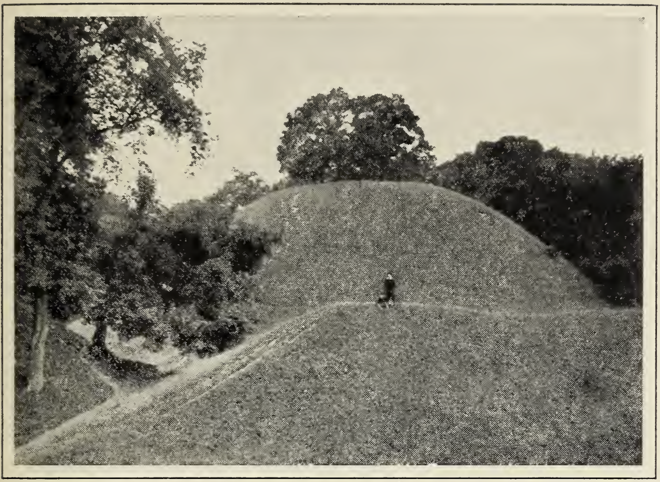
Bare soil cannot remain on hillsides

Examples of erosion, or wearing away of earth, as conspicuous as that just mentioned are noticed by every observing tourist. But did you notice the color of the brook or river after the last rainstorm? Somebody's good soil gave the water that color. Somebody's soil, including soluble minerals, was on its way down toward the ocean.

An expert from the United States Department of Agriculture has estimated that more than thirty million acres formerly cultivated in this country have been so worn away, or eroded, that they are no longer worth farming. He adds that "more plant food is removed every year by erosion than is used by crops."

Experiments with erosion in Missouri have shown that rains falling upon cultivated land may wash away one inch of soil in from one to seven years. It was further shown that nature takes an average of four hundred years to build up this inch of topsoil. And it may be worth while to add that topsoil, in which crops do most of their growing and from which they obtain most of their mineral

An inch of topsoil may be built in four hundred years and eroded in four



Ewing Galloway

Fig. 51. Grass holds Soil in Place and Prevents Erosion

How do you think it helps?

food, is seldom more than six or seven inches deep. In many places it is not so deep as this. Simplest arithmetic shows that bare land may be eroded in less than a generation of the wealth which it took several hundred years to collect.

To prevent erosion all sloping land should be kept covered with trees or grass. Look at the hillside in Fig. 51. Where it is absolutely necessary to use such land, it should be terraced, and grass should be left upon the slopes. If grass can be grown one year in three and cultivated crops grown the other two years, erosion is slowed down, since the grass roots remain in the soil. Alfalfa or clover may be used where necessary instead of grass, although the roots are not so thick. Gullies should be filled with straw and tree limbs while they are still small. No soil on sloping ground should be left bare at any time.

FIG. 52. Levees are used along the Mississippi River to hold the Water in Check

E. What are Some Steps in Flood Control?

Problems of flood control are closely tied up with problems of erosion. Nor can we find any better illustration of the connection between the two than in the case of our own Mississippi River and the area which it drains.

Each year the United States government spends millions of dollars building levees to "hold the river." A levee, as shown in Fig. 52, is an embankment of earth piled up along a river's edge in an effort to prevent the river from overflowing upon the land at that particular place. Two centuries ago early French settlers made the first levees along the Mississippi. They were highly successful. More people settled along the river, others at its sources. More and more people wanted their land protected. More levees were built. Two long levees parallel its banks for

Flood-control problems increase as more lands are cultivated

two thousand miles until the river has no room left for overflow. The result? It breaks through the weaker spots in the levees. It may destroy miles of them and flood millions of acres of crops.

Floods along the river are becoming worse each year. Is there more rain today? Does the river carry any more water than it did two centuries or even two generations ago? No, it does not. But the water used to trickle down through the forests and along through the grass roots, and stand a while in swamps and bogs. It might evaporate before it ever reached the river or run in a steady flow throughout the seasons. Today, however, over large areas, the means by which erosion was prevented are gone.

Good soil depends upon many factors. Among them are its composition and structure and its chemical content. Good soil for one crop is not good soil for another. Soil should be protected just as other natural resources are. Among the means for this are cultivation, fertilization, crop rotation, drainage, irrigation, and protection against erosion.

Can You Answer these Questions?

1. What factors of the environment are essential to plant growth? What evidence can you give to show the importance of each of these factors?

2. What different kinds of soil can you name? What are the essential differences between them? What relationship do these differences have to the value of the soil for plant growth?

3. Certain plants will grow only in acid soil, while others will grow only in alkaline soil. How may man treat the soil so as to provide these necessary essentials for plant growth? What is accomplished by plowing and hoeing?

4. What is meant by crop rotation? Why is it necessary?

5. Why is it necessary to fertilize some lands? What types of fertilizers are commonly used? What does each contribute to the soil?

6. What are legumes? What part do they play in enriching the soil?

7. What relationships are there between tree conservation and the problems of erosion?

8. Why do flood-control problems increase as more lands are cultivated?

Questions for Discussion

1. One organism living upon another kind of organism, as in the case of bacteria upon the roots of clover, taking something from its host but giving something also in return, is an example of symbiosis. Can you find other examples of symbiosis?

2. About 1910 a practical method was developed for making nitrogen compounds from nitrogen in the air. Could the great nations of the world produce enough food for their people today if this process had not been developed?

3. Until very recently in the United States land has been cheap and labor comparatively expensive. What effects has this had upon the upkeep of the land?

4. Do you believe, as some agricultural experts do, that some lands in the United States are so poor that they are not worth farming? If so, to what use do you think these lands should be put?

5. What conditions favorable to certain crops in Spain are not found in Mexico?

Here are Some Things You May Want to Do

1. Find a map of the United States showing the crops produced in various regions. From your knowledge of these regions and the conditions necessary for the growth of particular crops explain why each crop shown should be peculiar to that particular region.

2. If there is any clover growing in your region, dig up some of it and see whether there are any nodules on its roots. If possible, examine these nodules under a microscope and report on what you find.

3. It has recently been suggested that serious floods might be prevented by setting between the Mississippi River and the Rocky Mountains a belt of new forest running north and south. See what you can find out about this idea.

4. Examine some samples of soil under a microscope. Of what are the soil particles composed?

5. Make a demonstration to show that there are soluble substances in soil.

6. Find out whether or not the ashes left from burning wood are soluble in water. If the ashes do not dissolve in pure water, find out whether they will dissolve in water to which several drops of hydrochloric acid have been added. Separate the soluble from the insoluble part by filtering and then obtain the soluble part by evaporating the liquid.

7. Spread some soil over an iron plate and heat it very hot. What substances are removed from the soil by burning?

8. Weigh out equal samples of sandy soil and clay soil. Add to them equal quantities of water. The two samples should still weigh the same. Weigh both samples daily for several days. Explain the findings.

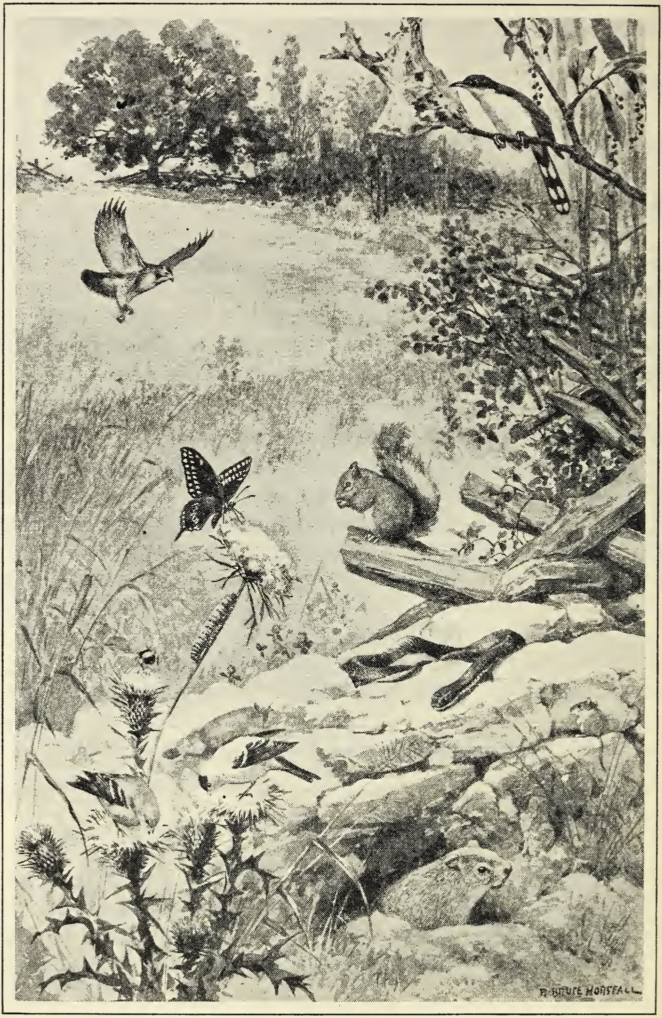


FIG. 53. The Factors influencing the Balance of Nature may be observed in the Everyday Environment

UNIT II

How has Man's Changing Civilization disturbed the Balance of Nature?



Chapter V · What is meant by the Balance of Nature?

Chapter VI · How has Man's Destruction of Forests disturbed the Balance of Nature?

Chapter VII · How and Why have we protected Certain Forms of Wild-Animal Life?

Chapter VIII · How have we attempted to control the Spread of Undesirable Plants?

Chapter IX · How are the Activities of Insects related to the Activities of Man?

IT IS extremely easy for man to think of himself as the master of this small earth. Many common expressions illustrate our feelings in this respect. Do these have a familiar ring? "Man, the monarch of all he surveys," "Man's conquest of the environment," "Man's superiority over other animals." How true are these statements?

You have found that man has taken great steps in his agricultural pursuits, but has he gone as far as he can or as far as he needs to go? Is there need for still better wheat, still better varieties of vegetables, or of still better fruits? Consider some other questions. How far has man gone in his control of bacteria? How wise has he been in his policies of conservation of forest and land? To what extent does he really control many of the insect and animal pests which injure his crops?

It is true that man has accomplished important things in his efforts to conquer his biological environment; nevertheless he has far to go. His knowledge is still limited, and he does not even use all the knowledge that he has.

This unit has been written in an attempt to show the characteristics of the biological environment and the part man has played in changing it. After you read it, ask yourself the question "Is man the monarch of all he surveys?" and see how you can answer it.

Chapter V · What is meant by the Balance of Nature?

A. How do Plants and Animals depend upon Each Other and upon Man in the Field or Forest?

In the chapters of the previous unit on man's environment you observed his relations to certain living things in field, forest, stream, and ocean. You studied native plants and animals and others that have been cultivated or domesticated. But for the most part you studied them separately rather than in their relationships with each other. Perhaps it would be fair to ask whether these various things have any relationships to each other. How can we find out? Suppose we look for a few minutes at a typical environment. Where shall it be? For our purposes we shall select a New England meadow. Why? New England, as you know, was settled at a very early time in the history of our country. The land was cultivated, and farms were common. Thus man disturbed the balance of nature. But what happened? With the sweep of people into the developing sections of our country farther west many of these farms were abandoned. The land went back to its natural state. Therefore our New England meadow is a good region to study, for regions may be found which in successive stages have been wild, have been under cultivation, and then once more have run wild.

In the frontispiece to this unit an artist has pictured such a meadow. Notice that it is fenced on one side by a stone wall which makes an excellent seat for observation. The other three sides are inclosed by a rail fence built some forty years ago.

As we view the scene, we see a hedge of hazel bushes and wild-cherry trees that partly conceals the rail fence. Were these bushes and trees planted there? Did their

growth begin before or after the fence was built? The answer to our second question is obvious, for the thicket runs along the fence on both sides and nowhere else. Its existence followed and was determined by the presence of the fence. Did someone plant this thicket? If so, it was certainly not the farmer who built the fence, for he had little use for either wild cherries or hazelnuts, and various shrubs growing there. Gray squirrels, hopping along the fence, were probably responsible for the nuts. Birds were very likely responsible for the cherry pits. Further, chance protected the young seedlings from plow and mowing machine. The seedlings continued to grow. Therefore the hedge, though unwanted by man, is a direct result of his work.

Thickets grow unwanted by man, but as the direct result of his presence

There is a large oak tree near one corner of the meadow. Was it too "planted" by a squirrel sitting upon the fence? In this case, no, for the tree is apparently much older than the fence. We cannot tell exactly how old it is without counting its annual rings; but since it is more than a foot in diameter, we guess that it is at least sixty or seventy years old. Oaks grow slowly.

Is the tree older than the meadow itself? Was it one of many in a forest? Let us see. This field is an old one. The farms in the neighborhood have been under cultivation for a hundred and fifty years or more. The old stone wall suggests that it has existed for at least a century. We can be fairly certain, too, that most of the life of this old tree has been spent in an open field, removed from the neighborhood of other trees. Notice the shape of the oak tree in Fig. 53; its horizontal branches, its rounded crown. It is not a tree that has had to struggle among other trees for a place in the sun. How, then, did it live through the yearly mowing or plowing and planting? Perhaps it was because there were no mowing machines, only scythes and sickles, when it was young. Did a farmer skip it purposely

Man's presence affects the growth of trees

Ewing Galloway

Fig. 54. Timothy Grass is grown for Hay

one year? Or was it protected by a bowlder just large enough to shield it from the blades? We do not know, but in all probability it would have been neither what it is nor where it is if man had not lived near.

It is July as we take these observations, and time for haying. Some sections of the region of abandoned farms are still cultivated. Timothy and redtop are grown for hay. Neither of these is a native grass, but they are among the best that man has developed to feed his animals. From the meadow on the other side of the fence will come four or five good loads of hay, for in this region such scenes as that shown in Fig. 54 are common. The farmer is depending on this feed, for his other fields are plowed and planted this year. Rotation of crops and intelligent upkeep are especially important if the owners of these smaller Eastern farms are to make a living from their land.

What of the animal life in this meadow? We see no large animals, although a deer with twin fawns often comes in the early morning or just at sunset, and there is a woodchuck hole down by the oak tree. But we do find many smaller creatures in the area. Are any of those in Fig. 53 familiar to you? Bumblebees and honeybees buzz over bunches of clover and wild buckwheat, going about their business of making a living while unconsciously aiding in

the formation of seed. This relationship and the story of how man has taken advantage of it are familiar to you all.

Carrot worms feed noisily on Queen Anne's lace. As you now know, they are not really worms, but the larvæ of what will later be idle blue butterflies. Most of them, however, will never see that day, and their combined eatings will do little damage to this beautiful but destructive weed. Why? A small parasite fly is busily laying eggs just under the skin of the smooth green caterpillars. More often than not, as you will learn later, *her* offspring will come forth from the butterfly cocoons, — victors over the rightful owners in the struggle for life.

Insects may live on other insects, holding them in check

Large black-and-yellow spiders glide out of their webs to devour flies, bees, and beetles trapped neatly in the spiders' silken mesh. Smaller spiders feast royally on fruit flies and aphids.

A five-foot black snake, basking on the wall close by, surprises and frightens us as it glides off into the grass. Our first impulse, to seize a rock and kill it, is a poor one, and fortunately the snake is gone before we can carry out our intentions. This particular snake lives almost exclusively on mice and moles, with occasional frogs and young rabbits for variety. It does more good in keeping down small animals like these than a dozen well-fed cats in the farmer's barn.

Life lives on life, to our advantage or disadvantage

A black snake will not harm a person in any way, nor indeed will any of the other snakes in the meadow. Even though you, personally, might not choose a snake as a pet, you should realize that except for three or four poisonous varieties in the entire United States — the rattlesnake, copperhead, water moccasin, and coral snake — snakes are economically of great value to every farmer. He has done himself much harm by killing the nonpoisonous ones.

A red-tailed hawk swoops down from the oak in the far corner of the meadow. You look about for chickens, but do not see any. Nor indeed does the hawk. He does not especially like chickens or any other birds. His search is for moles, mice, or young chipmunks, and he has just spotted one. Most hawks live on insects and small rodents (rats, mice, squirrels, and the like), more than 90 per cent of their food consisting of animals harmful to the farmer. Not all farmers realize this, and some draw a gun whenever they see a hawk.

Fig. 55. Tent-Caterpillar Web

Tent-caterpillar webs, like the one in Fig. 55, were pretty thick in the wild cherries a few weeks ago, but have now almost completely disappeared. We recognize the work as that of yellow-billed cuckoos, who have cleaned out the caterpillars nearly to the last morsel. We are reminded that these slim graceful birds with the curved bills eat many kinds of fuzzy, hairy caterpillars so destructive to green leaves, including the caterpillar of the gypsy moth and the tent caterpillar.

Flycatchers, vireos, warblers, and woodpeckers are busy with various other insects, while sparrows of many kinds, bobolinks, and bobwhites make way with weed seeds by the bushel. In a week or so the haying on near-by farms will be done. Then what a feast of mice and moles the hawks will have! What a picnic for the crows and grackles, who will attack the grasshoppers so temptingly exposed!

Birds eat insects and weed seeds, as well as rodents

And so we have seen the meadow as man made it. The plants and animals in it are things belonging to the meadow.

A meadow is a product of man's work

Next year or the year after, it may be plowed and then planted to vegetables. Ragweed pusley, pigweed, spurge, and blackheart will replace the weeds of the hayfield. The deer and the woodchucks will add beans, cabbage, and corn to their daily diet. There will be additional insect pests: potato bugs, squash bugs, corn-borers, and bean beetles. But the snakes, hawks, toads, and small birds will still be there. Life will not be greatly different. It will still be a farmer's field, over which, if he uses all the knowledge he has, he may exercise a large measure of control.

But this land has not always been an open field. It has not always supported good grass or corn and potatoes.

Forests were "conquered" only by great effort

Only a few generations ago it was unbroken forest. Our pioneer forefathers worked hard to change this land from uncultivated wilderness. Rugged old settlers pried great rocks from the topsoil, piling them up to make stone walls. They felled trees, dug out stumps and roots, and burned them. They had plows, with oxen to pull them. Finally, upon cleared land they sowed crops. But it was not easy. Forests gave way to fields and meadows only under pressure. Forests are features of the natural environment. Open fields in most parts of the temperate zone must be made by man.

B. What is the Natural Order of Events in Forest Growth?

How do we know that forests rather than fields are natural in this region of the world? Let us get up from the

Forests do not stay "conquered"

stone wall where we have made these observations and take a walk up a cart path into the woods of the cow pasture. We need walk only half a mile or so before coming to an opening where once was another farm, — the "Hyde place," we call it. Here

are two old cellar holes and many stone walls. Purple lilacs bloom in June by the cellar hole where the old house stood. Even now there are red roses in a clump by the stone doorstep. The old barnyard is still there, and a clearing in front of the house. This open space is due to a planting of locust trees covering an irregular area of perhaps two hundred by five hundred yards. Under these locusts grows grass, kept close cropped by the cattle, but there is no underbrush. Aside from this one open space the land is a tangle of bushes.

Other things creep in as time passes, if fields are neglected

In the "west pasture," where the stone wall is still in nearly perfect condition and the land free of rocks or stubble, grow fine high blueberries. You can pick a quart in no time. Black huckleberries were plentiful ten or fifteen years ago, but have been crowded out by the taller blueberry bushes. An occasional "pasture cedar" warns us that blueberries in their turn will give way to cedars. Here in this lot our grandmother remembers a melon patch.

Over the wall, behind the cellar hole where the house stood, is another lot largely filled with gray birches. There were chestnut trees before they were destroyed by disease, but only a few offshoots from the old roots remain. As the larger trees died and were cut for firewood, young birches took their place. In this lot are many wild grapevines, descendants of vines planted by the people who once lived here.

The rest of the place is woods, as thick with trees as if it had never been cultivated. In spring or fall you might spot an apple tree, silent reminder of human planting. Though still alive, it is hidden by taller trees above and dense underbrush below. It still yields fruit in some years; but since this tree is neither sprayed nor trimmed and is crowded on all sides by larger trees, the fruit is never worth harvesting. The old family cemetery is overgrown by scrub

oaks. The gravestones lie flat and broken. One marble slab records a death in 1877, but the other stones are of slate, dating back to 1794.

Nor is this old "Hyde place" the only New England farm that records a similar succession of events. Fig. 56 is a common scene. Within a radius of half a mile from the cultivated field in which we took our first observations are two "abandoned farms," some of the buildings still standing but long unoccupied, fields overrun with brush. There are six other places where cellar holes in the woods tell of farms deserted still earlier.

Man's "conquest" is often only temporary

Thus we witness the procession of events as told by fields and pastures. Man "conquered" the wilderness, plowed fields, made a living from the soil. Forests were replaced by cultivated acres. But other opportunities opened, perhaps on richer Western soil, perhaps in rapidly growing Eastern cities. The older generations died. Perhaps the soil through careless farming became exhausted. Farms were deserted; the wilderness again claimed them. Thus we see that man's "conquest" of his environment may be only temporary.

In the forest itself the succession of changes that may take place within a generation is no less marked. Upon this same farm where we made our observations of the field are wood lots of hardwood and softwood.

The softwood is chiefly white pine, which is valuable for lumber. The owners of New England white pines find it profitable to cut them once in about forty years. True, the trees would continue to grow for fifty or a hundred years, but there is always danger of forest fire. There is also the very human desire of wanting the money from the pines. Even forty years is a long time to wait!

One pine lot on this farm is now nearly ready to cut. From the house, as you look at this lot, the entire hill appears to be pine. Even in autumn no other trees show their

Fig. 56. Man's "Conquest" of the Wilderness is often Only Temporary

Are there any abandoned farms near you? Why were they abandoned?

presence. Nor is the green less dense in December. We look at it now and think back thirty years to the time the sawmill was there. We remember the stacked lumber and the piles of sawdust, young mountains they appeared to us. We ran barefoot through recently made cart paths. We picked low blueberries that sprang up in the pine-needle humus. There was trailing arbutus all over the hill.

Cleared wood lots begin at once to grow up again

But time passed. Tall blueberry bushes began to replace the low variety. Black huckleberries occupied the drier areas. Young birches sprang up on the hillside. Later, small oaks and chestnuts appeared among the birches. Cattle, turned in to pasture soon after the lot was cut, still kept the paths clear, still apparently found some browsing; but as the years passed, they stayed more and more in other parts of the pasture.

It has been twenty years now since cattle used this land at all and ten since we found blueberries there. The oaks, chestnuts, and birches have disappeared in their turn, although not entirely without human aid. The birches went first, crowded out by the taller trees. And as they began to die, they were cut to make firewood. The chestnuts died of disease. They too were cut.

There is a natural succession of growth

By that time small pines were in evidence among the other trees, and it was a matter for the owners to decide whether the pines were to be aided in their struggle for life or whether the pines and the oaks were to be left to "fight it out." It is probable that in the latter case the oaks might have won, with white oaks finally replaced by black oaks. The oaks in their turn might sometime in the future have been replaced by sugar maples and beeches. This is a natural order of events known to have taken place on other New England acres.

But here man interfered. White pine appeared to him more valuable. Oaks and maples, if large enough, may be

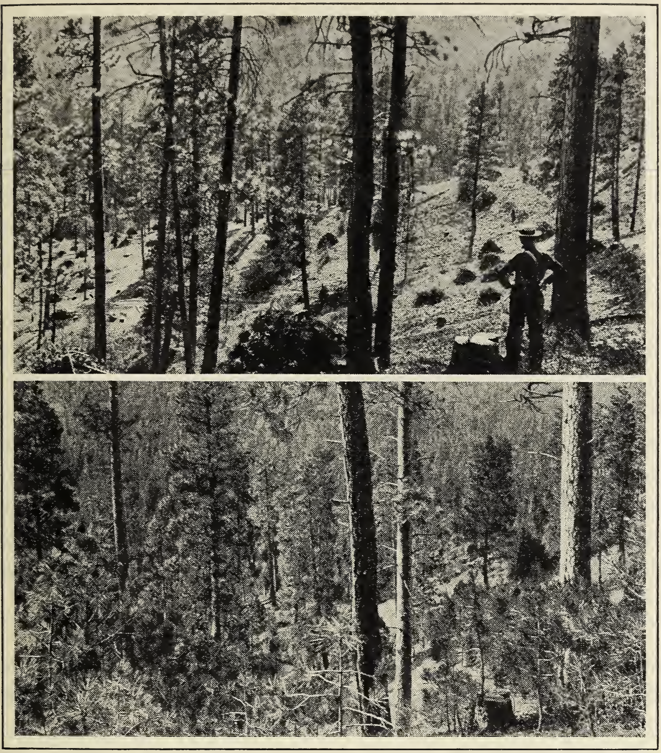


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FIG. 57. Large Areas of Woodland show Cycles of Growth

These pictures were taken years apart

used in making furniture, hardwood floors, and so on. But they grow very slowly. Accordingly the young oaks were cut and corded for firewood. Now the owners await a good opportunity to sell another pine lot. Another generation of children will watch the sawmill, play in the sawdust, and scoop blueberries from little bushes. The cycle, or round of events, in the forest is continuous.

Man may interfere to the advantage of one kind of organism

C. Why are Conditions in Nature continually Changing?

Balance in nature is a condition in which the various organisms, or living things, and the various physical factors in a given habitat are all more or less fixed. Life goes on in the same way over long periods of time. Any one organism depends upon many others for food, shelter, and other needs. It depends upon air, water, and sunshine. It neither increases greatly in numbers nor dies off completely. Conditions on the whole remain the same.

When you observe closely, however, you see that conditions do not remain the same. In a forest there may be fire; there may be woodchoppers and a sawmill; there may be a new insect pest or a strange fungus disease. The water in a pond may become impure because of waste from near-by dwellings. Oil used to kill mosquito larvæ may kill many other things as well. The pond may become filled with silt, or the dam give way. Small ponds may dry up completely. Then what of the balance of nature?

Conditions in nature are changing

An unusually dry summer or an unusually wet spring, a late frost or an early one, are among conditions that may affect balance — to say nothing of major disasters like earthquakes, volcanic eruptions, and floods.

In any given locality are certain plants and animals that are especially well fitted to it. After a natural disaster like a forest fire or a major change due to advancing civilization, which more or less completely wipes out the life in a given region, we may witness a succession of changes. Smaller organisms appear first, those whose seeds or eggs may be carried there by wind or birds or other such agencies, or those organisms that have been so protected as to live through the disaster. Soon newcomers appear. They may eat the first inhabitants, or they may simply crowd them out in the struggle for food and sunshine. Later these in turn give way to

Major changes disturb balance

United States Forest Service

FIG. 58. A Grove of Maple Trees represents Climax Organisms which may continue to hold the Habitat for an Indefinite Period of Time

other newcomers as the habitat changes. Thus gradually the life of the plant is renewed. At any time the plants and animals that are found there are those that can best live through intense competition; and unless conditions have changed greatly, the plants and animals that finally win out are those that lived there before the disaster. These *climax organisms* will continue to hold the habitat for an indefinite period of time, and a balance in nature will appear to have been reached. The maple forest of Fig. 58, in New England, is an example.

In time, climax organisms reappear

In the newer farm lands of the Middle West evidences of man's influence on the environment are to be seen on every hand. When the Indians roamed the plains, there

FIG. 59. Once upon a Time the Western Plains were a Vast Area of Prairie Grass

was a vast acreage of prairie grass similar to that shown in Fig. 59. Dense forests grew along the streams. The grass of the open plains and the cover of the forests each served as the habitat for plants and animals which were adapted to it. The bison (commonly called the buffalo) roamed the plains in enormous herds. There was a population of large and small animals adapted to life in the field, and another population of large and small animals adapted to life in the forest. Each environment had its own bird life, its own insect life, and its own reptiles. The animals and plants of the streams and lakes were also a necessary part of the "balance of nature."

Now it is all changed. With severe labor the plains have been plowed; and where the wild grass grew, there

is now the greatest production of wheat, corn, and cotton that exists anywhere in the world. The forests have been cleared, and the wood from the trees has been used to build the homes in great cities. Certainly man has in large measure brought this area under his control and is struggling to maintain this control in such a manner that the cultivated fields will continue to be sources of crops for food and clothing with which to supply the world. As we look over the fields of Illinois, Iowa, Kansas, Oklahoma, and Texas, we see the character of the changes that have come during one or two generations. These are changes that have come in fifty years. They are in striking contrast to the changes in New England, where man's influence has worked through a much longer time. It is interesting to inquire what this region of the West will be like in a hundred years. The answer will be determined by the manner in which man exercises his control over features now in evidence and by the extent to which he is equal to the demands of the new problems that arise as a result of changes for which he is responsible.

Wherever you may go, the greatest disturbance of all in the "balance of nature" is that caused by man. We have described at some length the succession of changes that have taken place in an old New England settlement. We have suggested briefly the changes that have come with man's "winning of the West." We have told you in previous stories of the damage man has done in allowing land to become eroded, or worn away. You will soon read of pests brought into this country through man's carelessness or ignorance, and of the damage they have done.

Man is often responsible when the balance of nature is disturbed

Take just a few other examples. Do you think man disturbed the balance of nature when he pastured cattle all over the country? Did he disturb the natural balance when he introduced the domestic cat to this continent? Does it make any difference that the average person dislikes

earthworms, loves gray squirrels, or fears snakes? What happened to the balance of nature when a sports-loving Englishman introduced rabbits in Australia or when a homesick Scotsman planted the first thistle in New Zealand?

But you may go on for yourselves. The examples are endless. Man has so changed the surface of the earth and the character of the other things upon it that it is sometimes difficult to think what it would be like without him.

Balance in nature suggests that the various organisms depend upon each other and upon the physical environment. Such a balance is continually disturbed, owing to major and minor changes in the habitat. A large factor in such changes is man himself. He introduces foreign organisms that often get beyond his control. He cuts trees, makes farms and abandons them, and generally interferes with the natural order of events. Greater understanding may prevent undesirable or unintentional disturbances.

Can You Answer these Questions?

1. How do climax organisms in a given area differ from those which preceded them?

2. Do snakes have any economic value? What evidence have you?

3. What definition can you give for the *balance of nature*?

4. Can you trace a succession of tree growth in a wooded area and explain why the succession takes place?

5. What examples can you give from this chapter to show how the balance of nature is maintained?

6. Similarly, what examples can you give to show how this balance may be disturbed?

7. Why do we say that man is probably the greatest disturber of the balance of nature?

8. What evidence is there that the fence described in this chapter is older than the shrubs along it?

9. What are the evidences that the oak tree described in this chapter has lived its life in the open field?

10. What are some of the things that might happen in a community if all the snakes were killed?

11. How does the cutting of hay in a field work to the advantage of hawks?

Questions for Discussion

1. Is there any such thing as a complete balance in nature?

2. The succession of tree growth and farm development traced in this chapter happened in New England. Do you think it has happened anywhere else? Why should it have happened to such a great extent in the New England area?

3. In what respects is the cycle of changes now in progress on the farm lands of the South and Middle West similar to the cycle which has taken place in New England?

Here are Some Things You May Want to Do

1. Do you know whether any poisonous snakes are common in your region of the country? If so, can you recognize them? Read about poisonous snakes and find what should be done in case you are bitten by a poisonous snake.

2. If you do not already have a balanced aquarium or terrarium in your classroom, ask your teacher to help you to set one up. Consider especially the factors you have to guard against in order to get a good balance in your exhibits.

3. Make a study of the succession of changes that have taken place in your own community.

4. Work out a food chain in which the black snake is one link. Try it for a toad, a yellow-billed cuckoo, a goldfinch, a hawk, an earthworm, and a blue swallow-tailed butterfly.

5. Make a field trip, if only to your own back yard, to find examples of different habitats. If you have a camera, take some pictures of scenes which you think best illustrate the balance of nature in various environments.

Chapter VI · How has Man's Destruction of Forests disturbed the Balance of Nature?

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Fig. 60. The Indian had Many Reasons for Wanting to save the Forests

With a sparse population there was no problem of forest conservation

In his conquest of the wilderness man has found it necessary to destroy many acres of forest lands, but he has without doubt destroyed some where it was not necessary. Some of the consequences of this destruction are described in this chapter.

A little over four hundred years ago Indians were the only human inhabitants of this country. It was a land of great forests, small streams, and lakes. Small mammals — skunks, foxes, raccoons, minks, possums, squirrels, and rabbits — fed upon the plant life or upon still smaller animals abundant in the sheltering forest. Through the vast stretches of woodlands roamed deer, moose, and elk, and over the grasslands of the Middle West roamed

the bison. All of them were hunted by wolves and mountain lions.

Through their midst stalked the Indian hunter, as in Fig. 60, anxious to get food or furs for himself and his family. Doubtless he enjoyed the hunt. Probably it pleased him to outwit and capture the wild things of the woods. But he killed only what he needed, and his needs were not great. Nor did he without reason kill trees. He felled some trees for fuel, used bark for canoes, and used branches as framework for his wigwam. But his demands upon the wood of the forests were never great. The living trees were worth enormously more to the average Indian than all the lumber that could be made from them. The forest sheltered him. It fed him. He loved it and was part of it.

A. How has the Forest been disturbed by the Advance of the White Man's Civilization?

If you will recall stories about the white pioneers, you will remember that these men are pictured ax in hand, "conquering the wilderness" (Fig. 61). Conquest in this case meant destruction of the forests.

The white man feared dangers in the forest

Why was the white man's attitude toward the forest so different from the red man's? In the first place, the pioneers feared the unknown dangers lying hidden among trees — wolves or foxes that stole their domestic animals, hostile Indians who crept so quietly from ambush to ambush that even the brush beneath their feet was silent. It is not surprising that the pioneer desired to get rid of the forests near his home.

He needed the room it occupied

Then, too, clearings for houses and barns, for corn or other crops, for pastures, for streets and public buildings and playgrounds, were soon needed. Little villages occupied sites claimed only a short time before from the forest. Pioneer farms were cleared land for only a few generations.

Fig. 61. Why has Conquering the Wilderness usually meant also Destroying the Forests?

And did not these pioneers need more wood than the Indians did? Look again at Figs. 60, 61, and 62. You will think of a dozen different uses for wood, suggested by the picture. If you should consider present-day civilization instead of that of colonial days, you would find that it has still more uses for wood. Modern civilization demands trees and forests, but it has less room for them than had primitive civilization.

He needed the wood it could give

But there is still another reason why trees were cut so freely by the pioneers. The vast wilderness was filled with them. The supply seemed unending. Who would think to save them or even to be careful in their use? As our growing population spread westward, there still seemed to be an abundance of forests. Look at the map in Fig. 63, which shows the extent of the forests of the United States before the coming of the white man. You see a broad band of forests

Forests were plentiful. Why save them?

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FIG. 62. Many Early Towns spread over Lands reclaimed Only a Short Time from the Forests

in the east, reaching from Maine to Florida. As you move west, you come to a stretch of open prairies where there is not sufficient moisture for the growth of wide forests. Farther westward, beyond the high mountains, you come again to extensive forest lands.

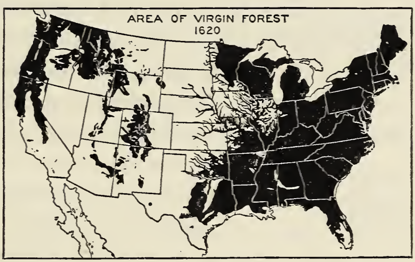

FIG. 63. The Coming of Man has meant a Change not only in the Amount but in the Kind of Forest Land we now have in this Country

The map shows forest areas before the time of the pioneers. Do you think a similar map for today would be different? Is there any virgin forest today?

Even though the population doubled and doubled again and again, — from three million at the time of the Revolution to a hundred and twenty million at the time of the World War, — there was timber for every need. But wait! Let us look at some figures. We no longer

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Fig. 64. The Government is now taking Definite Steps to protect our Forest Resources

have 900,000,000 acres of forests. Today we have only 550,000,000 acres. Only a little more than half as much forest, but more than forty times as many people!

The problems of forest conservation (that is, the saving of our forests), like the problems of saving our other natural resources, have occupied an increasingly important position in the thoughts of the American people. It is clear today that forests are no less likely to be exhausted than are coal, iron, or petroleum, but it is also clear that they differ from these other resources in one important respect: they may be replaced. And today the wise owner, whether government or private individual, is replacing them. For every tree cut he sees that another is planted, a policy that has been recommended for generations in Europe.

Today we must provide for conservation

Comparatively few sections that have deliberately been cleared of forests are being allowed to grow up again, for

most of the cleared land is needed for cultivation. But large areas worthless for cultivation that were carelessly cut over are being replanted. Some eighty million acres of land once covered by forests now lie idle, producing neither trees nor other valuable crops. These should be given attention. The underbrush that has grown up on them should be trimmed to give young trees a start, and in some places more valuable kinds of trees can replace to advantage less valuable varieties. Fig. 64 shows a group of government workers clearing out underbrush in a forest.

In a few sections of the country today so-called submarginal lands, not fertile enough to produce good cultivated crops, are being bought up by the government and replanted to trees. Such lands have supported forests in the past and will do so again in the future.

B. What are Some Definite Problems brought about in the Forest by Advancing Civilization?

Even in sections of the country where forests still remain, changes have come about in them because of the white man's presence. Probably chief among these changes is the frequency of forest fires. Then there is the loss due to insect pests and fungi. Let us look at these more carefully.

Forest fires must be controlled

Our annual loss from forest fires has been estimated at around $500,000,000, or about one third the value of our crude forest products each year. In such fires people and animals as well as timber are destroyed. Not only must we take into consideration the timber ready to cut, but the timber which the saplings would have produced if they had been allowed to grow to maturity. As the signs along the highways of one state put it, "When trees burn, everybody loses."

Ignorance and carelessness are responsible for most of the loss from fires, and the more people there are living or

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Fig. 65. "When Trees burn, Everybody Loses"

Will this forest ever restore itself?

passing near our forests the greater the loss may be expected to be. The loss pictured in Fig. 65 is a loss for which the presence of man is definitely responsible.

Control of fires is one of the most important parts of forest conservation. Such control depends as much upon an understanding of the scientific principles of fire control as upon the number of men who can be gathered to fight fires.

Let us review the conditions necessary for any fire: First, of course, there must be fuel. Second, there must be oxygen. Third, there must be a kindling temperature, that is, a temperature sufficiently high to start a fire.

In some way a spark falls upon dry leaves in the midst of dry underbrush. Both the leaves and the underbrush have low kindling temperatures. A flame starts through the brush. It mounts to the branches of some of the smaller trees. If they happen to be evergreens, it spreads more

rapidly than in hardwoods because of the tar and pitch, which have low kindling temperatures. A strong wind supplies it with oxygen and carries it up to the leaves of the taller trees. Now nothing prevents it from raging through the forest.

The fire continues until it reaches a wide state road. This it may not cross, for the flames cannot cross a broad band which offers them no fuel. But in still another direction, in which the flames can spread, are farm buildings, several hundred yards distant from the burning trees. Men work hurriedly to plow a ditch across the open field and around the buildings. At the same time other men pump water upon the roofs. The ditch removes the fuel in the path of oncoming flames. The water on the roofs reduces their kindling temperature so that flying sparks may fail to set them on fire.

How could this fire have been prevented? First, by removing leaves and bushes as well as other vegetation from the reach of sparks along railroads. Second, by removing underbrush from the entire forest.

When a fire first starts, it is often possible to smother it. This is why you may see men beating a grass fire with brooms or coats. This is why stepping on a match will put it out. It is also one reason why you pour water on a flame. Chemical fire-extinguishers smother a fire by surrounding it with a blanket of heavy gas which will not burn, such as carbon dioxide or carbon tetrachloride.

During the years 1933 and 1934 more than three hundred thousand young men were at work in the Civilian Conservation Corps. Most of them were assigned to forest reservations. These young men in less than one year constructed enough miles of truck roads through the woods to encircle the earth at the equator. These roads at more or less regular intervals through the forest serve as firebreaks by providing lanes across which flames cannot pass, and they help men and equipment to get into the woods quickly to fight fires

Fig. 66. Forest Rangers are constantly watching for Fires

that have started. The young men also laid fifteen thousand miles of telephone wires, so that news of a fire could be spread rapidly and help be secured before it was too late. They removed underbrush from a million acres of forest and developed two thousand acres for airplane landing fields.

Forest rangers (Fig. 66) are on duty in the national forests at all times. From lookout towers and airplanes they are constantly on guard in order to locate fires while still small. As soon as a fire is discovered, men and equipment are rushed to the scene.

During a period of prolonged drought, when there is more danger of fires than usual, conditions of the atmosphere are watched carefully. During hot, dry weather men are taken from other duties and are held ready for immediate call in case a fire breaks out.

A second important part of forest conservation is that of insect and fungus control. While it is entirely practical to

spray or band shade trees and trees in small parks, it is much too expensive to undertake such measures in forests. In a few cases forest trees have been sprayed from airplanes, but the cost was very great. (A spray is a solution of a chemical, poisonous to insects or fungi, which is sprayed upon the leaves of trees in order to kill pests.)

Insect pests must be controlled

Some fungi may be wiped out by destroying a second plant upon which they live part of the time — the currant bush, for example, in the case of white-pine blister, and the English barberry in the case of wheat rust. You will learn more about these later. This suggests the need for a thorough knowledge of the life history of the organism that is doing the damage. In the war upon the white-pine blister state foresters scouted the woods and pastures of New England and other places, destroying all currant bushes and related shrubs. As a consequence many white pines were saved.

The spread of insect pests is often delayed by strict quarantine. This method has been used with doubtful success in attempts to control the Japanese beetle, now prevalent in New Jersey and parts of Pennsylvania, New York, and New England.

A more lasting measure is that of discovering some natural enemy that will destroy the pest, but it must be an enemy which is not itself a pest. Birds are important natural enemies of insects — a chief reason why all of us should try to protect bird life.

C. Why are Forests still Needed? Why do they have a Place in Today's Economy?

"But," perhaps you say, "maybe we don't need great forests. Maybe other products are going to replace those of the forest, as oil has replaced coal for some purposes, as iron has replaced stone and copper for other purposes,

Fig. 67. Are Forests still Needed?

Could you suggest other uses for wood?

as electric lights have replaced torches and tallow candles. Perhaps we are not going to use so much wood in the future."

Let us see. Look at Fig. 67. Figures show that we are using trees just about four times as fast as they are growing.

Will other products replace wood?

In one year, 1932, we used ten billion board feet of lumber, most of it from the West. What other substance could replace lumber for building purposes, for furniture, and for its many other uses? There are other substances, perhaps, but could they be produced as cheaply? Would they be as satisfactory? These are questions that will need answering, especially if our forests are further reduced. Will they be? If you have seen the waste left by careless lumbermen or have

Fig. 68. Our Forests are disappearing rapidly under Lumbering Methods Such as These

seen the effect of careless, large-scale lumbering, as in Fig. 68, you realize that here is indeed a serious problem.

The state of New York in 1929 produced nearly two million cords of firewood. You may expect this figure to drop somewhat in the future, perhaps, as coal and oil are used more widely for fuel in rural districts. But where firewood is near at hand, it will doubtless still be used in large quantities unless it becomes so scarce that it will be too expensive for most people to buy.

Still another use for wood is illustrated in the following statement: "It takes sixteen acres of spruce trees to make the paper for one Sunday edition of a metropolitan newspaper." Did you realize that one and a half billion cords of wood are made into pulp wood each year and used in the manufacture of paper? This figure will probably become larger rather than smaller in the future, because almost all paper is now made of wood.

Rayon and cellophane are made from cellulose. This cellulose may be obtained from trees, cotton, corn, or other vegetation. The demand for these products is increasing rapidly.

Trees and forests, as you have already learned in your previous science work, are important agents in preventing erosion and destructive floods. Forests are important, too, in maintaining a steady water supply, for they hold the water around the roots of the trees, allowing it to run off gradually.

National parks are sanctuaries for wild life

Forests serve also as game refuges and sanctuaries for wild-animal life. Outstanding in this line are the national forests and parks. Probably you think at once of Yellowstone Park, with its tame bears and herds of bison, but other parks serve as well for birds and animals of many kinds. Perhaps no better statement could be made regarding the importance of forest protection than the one made by Theodore Roosevelt years ago:

> Wise forest protection does not mean the withdrawal of forest resources, whether of wood, water, or grass, from contributing their full share to the welfare of the people, but on the contrary, gives the assurance of larger and more certain supplies. The fundamental idea of forestry is the perpetuation of forests by use. *Forest protection is not an end of itself; it is a means to increase and sustain the resources of our country and the industries which depend upon them.*

Forest acreage is steadily diminishing, while population is increasing. Wide destruction of forests means loss of lumber supply, drought, erosion, and destruction of the forest habitat with consequent loss of wild life. Fires and invasions of insect pests are increased in the forest by the presence of man. Steps must be taken to control these dangers.

Can You Answer these Questions?

1. What are the most common causes of destructive forest fires? Can you support your answer with concrete examples?

2. Why did the pioneer in America fear the forest? Did anything else but fear cause him to destroy the forest?

3. What chief differences are there between the way in which the Indian used the forests and the way in which the white man has used them? Who used the forest more wisely?

4. To what extent have the forest areas diminished during the last century or so?

5. How important a factor are forest fires in our waste of forest resources?

6. To what extent is the government attempting to guarantee the conservation, or saving, of forests?

7. What part did the forests play in guaranteeing a large enough water supply?

8. What did Theodore Roosevelt mean when he said that forest protection is not an end in itself?

Questions for Discussion

1. Why are the forests different in character in different parts of the country?

2. Is it possible that substitutes may be found for certain tree products which are now used widely? Can you think of any that have been found?

3. Should our government spend money to plant trees as windbreaks in certain sections of the country? Of what importance are they? Why is not the planting of windbreaks a matter for the individual owner if he wants them?

4. If a shortage of lumber should ever occur, would it not be wise to cut the trees in many of our national forests?

5. Can you account for the bad floods and the erosion problems that are so common in China?

Here are Some Things You May Want to Do

1. We have suggested in this chapter that lumbering in the various countries of Europe differs greatly from that in this country. You may wish to make a special study of these differences and to discuss whether or not Europe has a more sensible outlook upon the importance of lumber and forests than we have in this country.

2. You can secure booklets and other materials on forestry from the Forest Service, Department of Agriculture, Washington, D. C., or from the American Tree Association, 1214 Sixteenth Street, Washington, D. C. If you write, be sure to make it a class letter and be sure to give the people to whom you write some idea of what you are looking for.

3. If you have a lumber dealer in your community, visit him and see what you can find out about the types of lumber most commonly used. Which is the most popular? Where does it come from? Why is some lumber more expensive than others? There may be some other questions of special interest to you.

4. Start a tree nursery in your school, with the idea that trees will later be planted where they may grow to maturity. Where will you get your young trees? Some states furnish them at little or no cost to people who will use them wisely. Investigate your own state and see whether this service is provided there.

5. See if you can find any dens of small animals in your neighborhood. Perhaps you would like to photograph them. How can you secure pictures of the animals in their native state?

6. Show on a map the regions of the United States where farming is now carried on but which might better be turned back to forests or grasslands.

7. Prepare an exhibit of samples of the native woods in your community.

8. Place some wood chips in a test tube and heat them. What commercial products were once obtained from this source but are now obtained from other sources? Consult an encyclopedia.

Chapter VII · How and Why have we protected Certain Forms of Wild-Animal Life?

A. What are Some of the Benefits that Man has derived from Animals?

Think of the debt which we owe to animals. You may picture a primitive man with stone and sling in his search for the wild deer or hairy mammoth. You may have in mind a scene near a modern slaughterhouse, where hundreds of animals are driven to death for one day's food supply. Or you may glimpse a jungle pygmy stalking wild fowl, or a fur-clad Eskimo spearing seals in arctic waters.

In any case what motives lie behind man's never-ending pursuit of wild animals or his concern for those so carefully domesticated?

Man has used animals for food and clothing

"Food," you answer. Man has always needed animal food, as we do today. The Eskimo, the man of the jungle, the modern business man, the child at play, or the old man who totters down the street, — each needs some meat in his diet. And for this meat he depends upon animals. But you will think of many other ways in which we have used animals. You may picture a completely fur-clad person of the frozen North, a woman wrapped in an expensive winter coat of mink or ermine, a boy in a leather jacket, or a lumberman in stout leather boots. You may think of animal skins used for tent coverings, water-containers, straps, belts, and a hundred other purposes.

Food, clothing, shelter, — for these purposes we have used the dead animal. What of the living animal? Long before the dawn of recorded history man discovered that he could make use of the milk and eggs of certain animals. These he domesticated. He discovered also that animals might be made to do work for him. He learned to make

Fig. 69. Man uses Animal Products for Many of his Essential Needs

What should you have added to this picture?

use of wool and camel's hair, of alpaca or other hairy coverings of living animals. And he discovered that animals are good companions. Does Fig. 69 suggest any of these uses to you?

Man has protected animals that destroy his enemies

Some animals have been used to protect us from other animals. You think at once of the dog that keeps off wild animals, that tends sheep, or that serves as watchdog. You think of the cat that has a reputation for keeping mice and rats away, of the mongoose that attacks the deadly Indian cobra, of toads and birds that live on insects. Man has exercised an interest in these and other animals that help him in destroying harmful organisms. In some cases he has taken great pains to protect them.

B. Why have Certain Wild Animals needed our Protection?

As man has become civilized and gained increasing control over his surroundings, his interest in animals has come to be much more than just a general interest. It has become necessary for him to do something about it. He has found in a civilized world that many wild animals need his protection. Why?

Let us review the situation here in the United States as it has changed during the past few generations. Early white settlers found a land rich in wild life: mammals, birds, fish. In vast stretches of forests lived some four hundred different kinds of mammals (animals that give milk to feed their young) and many more kinds of birds. Rivers, lakes, and seas furnished food of other kinds in abundance.

Habitats have been destroyed

But conditions have changed. As forests have been cut and the Great Plains cultivated, deer, elk, caribou, and bison have been limited in their natural habitat and limited in their food supply. These animals can no longer roam the forests, for the forests have been replaced by plowed fields, broad streets, and tall skyscrapers!

Swamps have been drained to make room for cultivated meadows. The ducks, geese, herons, and muskrats that lived in these swamps cannot live in the meadows. Oil, poured on water to kill mosquito larvæ, has killed ducks, geese, and other waterfowl by the thousands.

In order to use the water power we have built dams in many of our brooks and rivers. But in so doing we have made it impossible for millions of salmon, trout, shad, sturgeon, and certain other fish to get to their spawning grounds. Consequently many of them have died without spawning.

Animals have needed protection against the greed and ignorance of a rapidly increasing human population. They

Massachusetts Division of Fisheries and Game

Fig. 70. Such a Kill as this was once considered Proof of "Good Sportsmanship"

A true sportsman of today would call this disgraceful

have needed protection against greed because the white man, unlike the Indian, has killed many more animals than he needed. Do you think there is any excuse for the kill shown in Fig. 70? The white man has slaughtered wild birds and sold them in the open market when a bird dressed and ready to eat meant only a mouthful of food. He has trapped animals for their fur because he could make a little money or a fortune from its sale. Nor was it until the supply was almost gone that he began to worry about it.

The white man has ignorantly killed animals for profit and for fun

And there is ignorance. You might think it evident enough that if birds or mammals are killed more rapidly than they can multiply, then these animals soon will become extinct. But our ancestors were too busy making a living to worry about how or when or where wild animals

produced others of their kind. The early settlers were generally ignorant about food habits, breeding habits, and other characteristics of wild animals.

C. What Characteristics have caused Certain Animals to be Exploited?

But let us consider some of this wild life at greater length and see if there are special reasons why certain animals have been in danger.

We have mentioned the elk and others of the larger animals. It is easy to see that there is not room in this country today for the herds of large animals that lived here during the time of the red man. The country itself has been too much changed. How about the American bison, or "buffalo" as it is incorrectly called? These huge beasts were a part in the balance of nature that prevailed before the Western Plains were plowed. They ranged over a third of North America, and were numbered by millions in the days before the coming of the white man. They lived in herds upon the prairies and neighboring woodlands. As the white man began to settle in the West, bison herds became smaller and smaller. In the first place, the big animals were in the way. There was neither room nor food for them. In the second place, their skins and fur were of some value. "Buffalo" robes were found in every carriage or sleigh and upon many floors. Bison flesh made good food not unlike beef. Finally, these animals lived in herds. A solitary animal often has a chance to hide, even though he is large and the hiding place small, but a herd has no such chance. Not one but many animals in a herd were killed when hunters on horseback came upon them with rifles.

The American bison is big and lives in herds

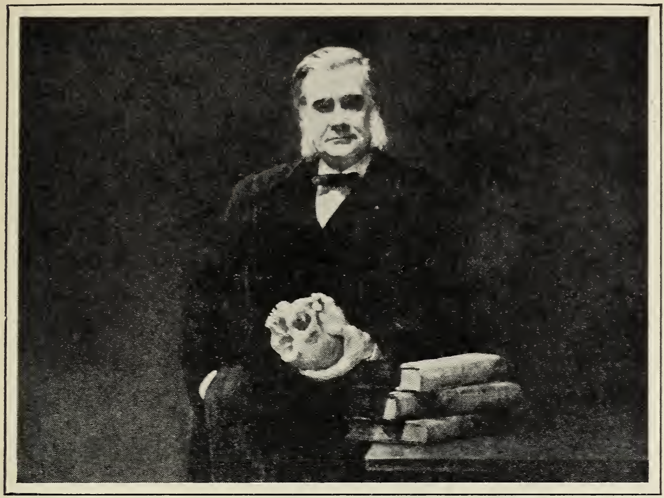
In 1889 the bison became so scarce that less than 1000 were left on the whole continent. Of these, 256 were in

captivity in parks and about 550 were running wild in Canada. Less than 200 were wild in the United States. Their value, except as a picturesque reminder of the past, was gone. Then the government became interested and decided to protect them.

About 1900 the idea of Federal ownership of herds began to be popular. The Yellowstone Park herd was founded in 1902. The Wichita national bison herd, with fifteen animals, was founded in Oklahoma in 1907. In Canada a still larger herd was created near Wainwright in Alberta. Under protection in these reservations these herds increased until in 1933 the number of bisons in America was nearly eighteen thousand. Therefore you may again see large herds of bison today in certain areas. This comeback of the nearly extinct bison is proof that wild life may be protected when sufficient interest is aroused so that the needs and characteristics of the animals are studied. The American bison will probably never be as numerous as it was in the past, for it can never range over the same vast territory. But there are many acres of land in the western United States and Canada not needed for other purposes and unfitted for domesticated cattle, where the bison under protection and possibly semidomesticated may live and multiply.

Passenger pigeons migrated in huge flocks. They were good to eat

The fate of the passenger pigeon offers an illustration of the disappearance of an animal probably more numerous, a short time ago, than any bird now living. This wild pigeon (Fig. 72), somewhat smaller than the common domesticated pigeon that you see in city parks and slightly larger than the mourning dove, was a migrating bird. It flew south in the autumn in huge flocks and returned again in the springtime. It covered a range from northern Canada to the Gulf of Mexico and from the Atlantic coast westward to the Great Plains. It nested mainly in the northern parts of the United States.



National Portrait Museum

FIG. 71. THOMAS HENRY HUXLEY, *who fought for his Scientific Beliefs (1825–1895)*

THE VICTORIAN AGE in England has come to suggest many things, but perhaps there was no one man belonging to that period who better represents it than Thomas Huxley. A brilliant youth, he read continuously. He spent his spare time with his two brothers-in-law, who were physicians, and when sixteen he was apprenticed to a physician. Entering a hospital a year later, he had three years of the most thorough medical training that could be had at the time · At twenty he joined the navy as assistant surgeon on H.M.S. *Rattlesnake*, which was starting upon a trip to the northeast coast of Australia. This trip had an untold influence upon Huxley's life, for it gave him a chance to study natural history on a broad scale at first hand. He made observations of all kinds of life, from jellyfish to Australian natives · A splendid lecturer and an excellent teacher, he soon won a place for himself at the School of Mines in London, and there he taught for thirty years. In those days it was not at all unusual for one man to be an authority on fossils, general biology, anatomy, and anthropology. Huxley taught all these subjects. Owing in no small measure to Huxley, we live in an Age of Science. The Victorian Age could hardly be called that · Professor Huxley did much to make science and the scientific method popular. As a teacher he trained a small army of young men who, going out later as educators themselves, won a place for science in the education of every boy and every girl. As a scientist he influenced the thought in every branch of biology to which he turned his attention.

A. M. N. H.

FIG. 72. The Passenger Pigeon was once a Common Bird

Above is a picture of a museum group showing this now extinct bird in a natural setting

All nineteenth-century observers agree about the large numbers of these birds. John James Audubon and Alexander Wilson have given descriptions of flocks so large that the birds broke limbs from trees where they went to roost, and so numerous that they darkened the sky as they flew overhead. Lines of birds nearly a mile wide were so long that it took them three or four hours to pass over one spot! These flocks ate enormous quantities of food and were very destructive to regions over which they flew.

When a flock of pigeons appeared in the spring, the whole community turned out to shoot them. Several might be

Arthur A. Allen

Fig. 73. The Mourning Dove, a Close Relative of the Passenger Pigeon, can still be Found

Does the text give you any hint as to the reason why?

killed at a single shot from a shotgun. In addition the birds were snared in huge nets at "pigeon stands," where, tempted by food, they were caught by the thousands. Birds caught at these stands were dressed and sent to market.

Pigeons in such large numbers may have been a nuisance. They were certainly very tempting to the man who could snare them and sell them. They were good to eat, and cheap. Doubtless many of them might have been killed each year without loss, but we killed too many. We killed without thought of the future. We left no birds to breed. The mourning dove, a close relative of the passenger pigeon and pictured in Fig. 73, has escaped a similar fate because it lives in pairs rather than in large flocks and because it never was so numerous as to attract widespread attention. The last passenger pigeon of which there is any record died in 1914.

One of the animals that has been slaughtered because of its fur is the seal. There are several different kinds of seals and sea lions, some of which have very little hair or fur. But the fur seal which lives in the waters of the northern Pacific and upon the Pribilof Islands off the coast of Alaska is covered with a beautiful, fine, soft, brown fur. Scattered through the fur are long stiff hairs which protect the softer fur while the animal is in the water, but these hairs may be plucked out easily when the fur is prepared for market. The seal is a comparatively large animal, and its skin, though soft, is tough. These two characteristics make it valuable for its fur.

The seal was slaughtered for its fur

Fur seals spend the greater part of the winter in the ocean and may spread as far south as California or Japan. When spring comes, they find their way north again to the islands that have been their exclusive breeding grounds for countless generations. During the nineteenth century hunters from Russia, Japan, Canada, and the United States found it profitable each spring to kill these animals in the waters near their breeding grounds, for there they could take them in large numbers. Such killing was referred to as pelagic sealing (*pelagic* being from a Greek adjective that means "sea").

In pelagic sealing animals were usually speared or shot in the water, and a sizable proportion of those killed sank before they could be recovered. Besides, while the seals were in the water, there was no way of telling which were males, which were females, or which were young animals. Between 1867 and 1869 more than 300,000 seals were killed in Alaskan waters, and this rate of slaughter continued until about 1900. In 1910 only about 132,000 fur seals remained in the world.

In 1911 a treaty was signed by the United States, Great Britain, Russia, and Japan, making the Pribilof Islands a fur-seal reservation under control of the United States

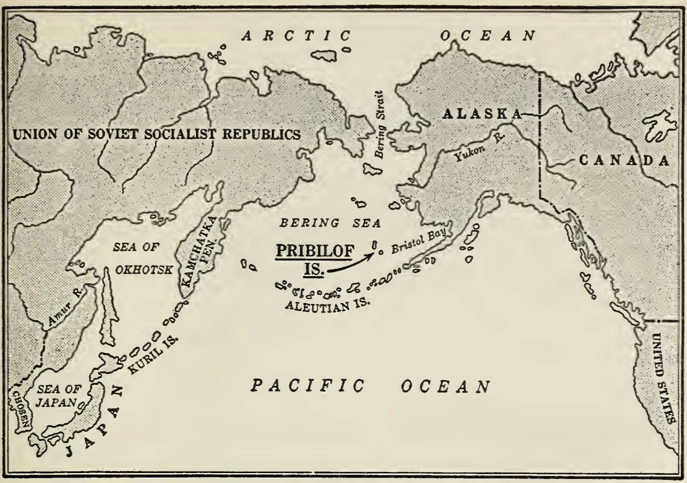


FIG. 74. On the Pribilof Islands are found the Largest Herds of Fur Seals Today

Many nations are interested in this reservation. Perhaps the map will help you to understand why

government. The map in Fig. 74 will show why these particular countries were interested. All four countries were to share in the annual proceeds from the reservation. Pelagic sealing was declared unlawful at any time. Today the surrounding waters are carefully patrolled, as shown in Fig. 75, *B*, to prevent violations.

A study was made of the life history of the seal. It was learned that as the animals came upon the islands to breed and rear their young, the old males came first. Each male, or "bull," chose his own particular territory, and upon this area he allowed no trespassing. The more powerful individuals gained what seemed to be the most desirable sites near the shore. The young, half-grown bulls were forced to take what was left, some distance inland. In early June the females appeared. A bull near the shore might secure from ten to twenty females to live within his exclusive

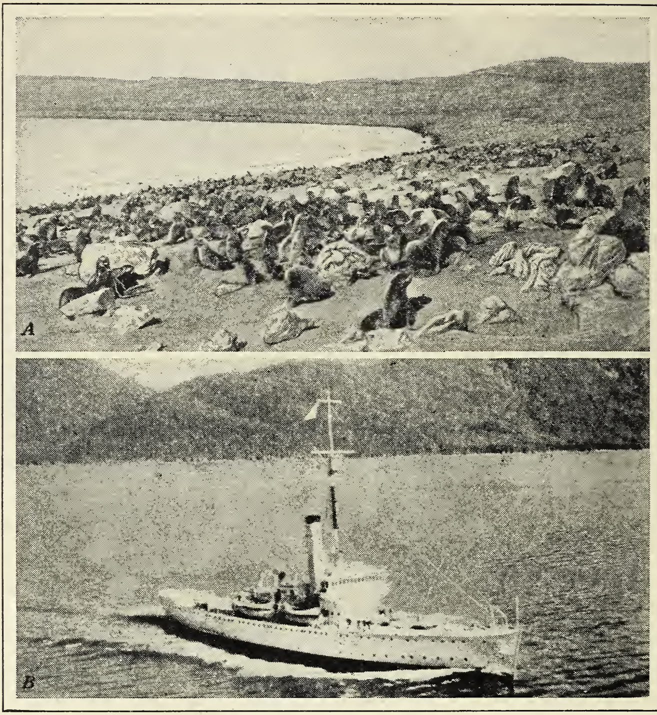


Fig. 75. By 1910, Owing to Reckless Slaughter, there was a Possibility that the Fur Seal too would soon become Extinct

Today, as the result of action on the part of all interested nations, the fur seal again flourishes. *A*, a typical seal reservation; *B*, the type of patrol boat which protects the seal against illegal hunting. There may be thousands of seals in a reservation

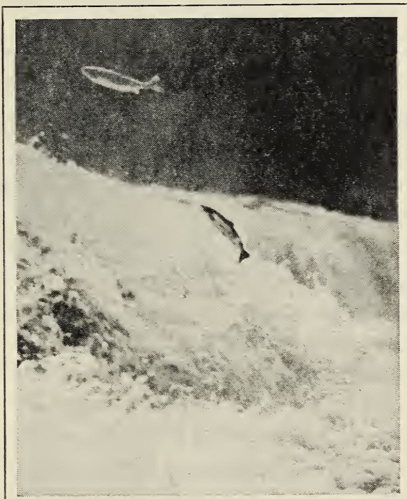
territory. The young which were born a few days after the females came ashore in the spring remained with their mothers all summer. Naturally the fighting on the part of the old bulls left most of the young ones without mates. When the men in charge of seal protection had learned these facts, they decided that some of these young males might be killed without in any way disturbing the

life of the rookery, as the breeding place of fur seals is called. Indeed a scarcity of males would simply mean less fighting the following season. Accordingly, only young male seals are killed today to make fur coats. In the twenty years between 1910 and 1930 the population of the seal rookeries on the Pribilof Islands has increased from 132,000 animals to nearly 1,000,000.

Knowledge of family life led to the killing of only young male seals

But let us take another illustration from a very different habitat. Let us consider the salmon, the fish that in one large river supplies us with some twenty million pounds of canned fish each year. The salmon migrates each spring to a spawning ground many miles removed from its winter home. Nor is the salmon the only fish that migrates. Eels, trout, shad, and sturgeon migrate as robins and wild geese migrate, and in even greater numbers.

Salmon and other fish are killed when they migrate



Ewing Galloway

Fig. 76. Not even Rapids can stop the Salmon on the Way to their Spawning Grounds

Salmon once were numerous in nearly all our rivers on both the Atlantic and the Pacific coast, but our chief supply comes now from Alaska and the rivers that empty into Puget Sound. In early spring they swarm up the rivers in schools of millions. They jump the rapids and pass dams which it would seem they could not get by. Can you see the salmon in Fig. 76? It is surprising to

Ewing Galloway

Fig. 77. Salmon are among the Most Important of our Food Fish

Canneries such as this have reduced the supply of salmon

note that when they arrive at a place where two streams meet, all choose one stream, although to an observer the other looks equally inviting. It has been found that they always choose the coolest part of a stream, which is also the part richest in dissolved oxygen. The oxygen is apparently especially important to them at spawning time, both for more vigorous breathing and for hatching the eggs and supplying them with air. Indeed, the migratory journey may be described as a journey in search of oxygen. The salmon goes even farther than most other migratory fish, straight to the streams near the mountain tops. These mature salmon spend from four or five months to a year in fresh water, and most of them die there. A few return to the ocean. The young fish are hatched the following spring. Since each female lays several thousand eggs, it is easy to see that there are many young fish. All of these that are to mature must succeed in getting back into the ocean.

Now let us see what has happened. Why has our supply

of salmon, as well as of other migratory fish, diminished in recent years? How have we disturbed conditions under which these fish have lived?

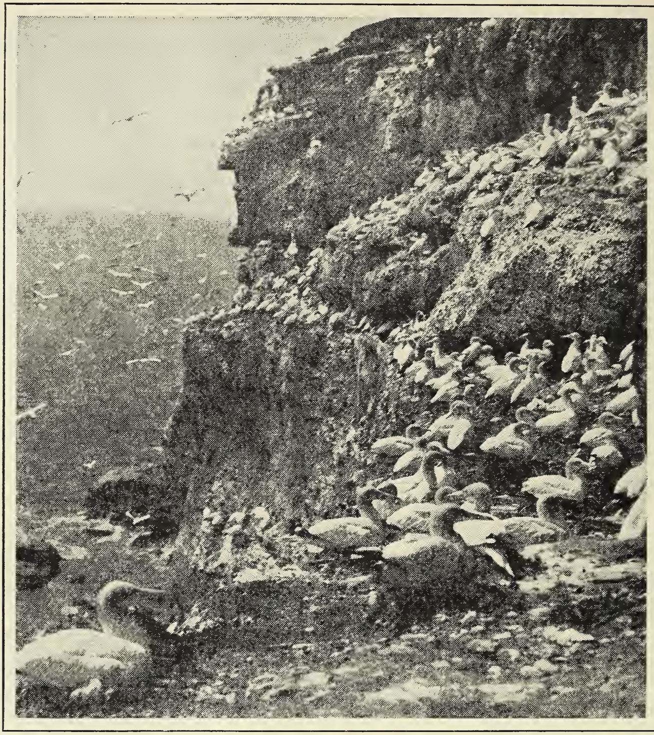
First of all, you may think that we have killed too many of them for canning. This is doubtless true. Have you ever visited a salmon cannery? Look at Fig. 77. Wholesale methods of catching the fish as they come upstream, economy in canning, ready demand for all that is canned, — all have seriously reduced our supply of this valuable food fish.

Massachusetts Division of Fisheries and Game

FIG. 78. The Pollution of Lakes and Waters is helping to destroy our Fish

Decay produces waste products and takes oxygen from water

But are there other reasons? We mentioned the dams in the rivers, built to supply water power. Unless special runways are left, it is difficult or even impossible for the fish to pass some of these dams in going upstream. This of course means a loss, because the fish die before spawning. Then, too, these dams may prevent the young fish from getting downstream. Irrigation ditches have been responsible for the death of many other young fish which, having gone down them, found no outlet. Sewage and waste from chemical plants have polluted the rivers and are without doubt responsible for further losses. The scene in Fig. 78 is the result of such pollution.



Armstrong Roberts

FIG. 79. Many Nations of the World are setting aside Certain Areas as Sanctuaries for their Bird Life

Knowledge of life habits should mean protection of valuable wild life

With these few illustrations of exploited animal life we have attempted to show how man, knowing their habits and life histories and profiting by past mistakes, might protect valuable animals. While covering the land with his own civilization man has changed to a considerable extent its animal life. Careful study and observation may help him in making changes that are to his own advantage as well as to the advantage of generations to come.

D. What Attempts have we made to protect Wild Life?

In describing the exploitation of the bison and the fur seal we showed also how efforts had been made to protect them. You may know, too, how the United States has set aside lands for national parks and wild-life reservations.

Conservation departments have been established

Conservation, or protection, of resources becomes important to the average person only when he begins to find a shortage. Accordingly conservation as a national policy and as a topic of popular interest first appeared about 1890. Within the last forty years our efforts at conservation have, according to William T. Hornaday, ranged all the way from elephants to oysters and have included a recent attempt at preserving the great whales.

Massachusetts Division of Fisheries and Game

Fig. 80. Game Wardens Play an Important Part in the Conservation of Wild Life

Do you know the duties of game wardens in your state? Do you coöperate with them?

The United States Bureau of Biological Survey came into being in 1885. It now enforces conservation laws relating to interstate commerce in game and fur animals, to the protection of birds on reservations (similar to the one in Fig. 79), and to the migratory-bird treaty with Canada. It maintains preserves and sanctuaries

Fig. 81. Certain Methods of Hunting are now Illegal in Many States

Why do you think the method shown here should be considered illegal?

for birds and big game. It carries on research and experiments relating to fur farming, game farming, and the reindeer industry in Alaska. It serves as a clearing house for information on wild-life conservation. The Forest Service protects wild life in national parks, while the United States Bureau of Fisheries is responsible for the protection and breeding of food fish, including shellfish. Of course shellfish (clams, lobsters, oysters, and scallops) are not fish, but their conservation is just as important as that of the fish we have been discussing. The Bureau of Fisheries cares for the salmon fisheries and the fur sealing on the Pribilof Islands.

In addition to these agencies of the Federal government most states and some towns have game wardens whose duty it is to see that local regulations are maintained (Fig. 80). They must see to it that hunters and fishermen have permits, for which they have paid, and that they hunt or fish only at certain seasons and under certain conditions. In nearly

Game wardens maintain local regulations

Armstrong Roberts

FIG. 82. Many Large Estates today are "Posted" against Hunting and Fishing

Do you think the owner of such land is justified in "posting" it?

all localities "spring shooting" of any animals is now forbidden, because this is the breeding season and shooting at this time means heavy loss of young. "Night shooting" is prohibited in many places in the case of birds because birds migrate in largest numbers at night. Fig. 81 illustrates an example of illegal deer-hunting. Certain animals in danger of being entirely destroyed may not lawfully be killed at any time, while the "open season" for others is only for a few days in late fall or early winter. Likewise the fishing season is limited, and only fish larger than a certain

There are closed seasons in hunting and fishing

minimum length may be taken. Market shooting and fishing with nets are also strictly regulated where not entirely prohibited.

In addition to the many public agencies there are countless private sanctuaries for birds and other animals, and many organizations interested in conservation of wild life. Golf courses have come to be used commonly for bird sanctuaries, while many large estates "posted," as in Fig. 82, against hunting and fishing at all times serve also as homes and safe breeding grounds for birds and mammals.

As illustrations of organizations formed for the protection of wild life there are the National Association of Audubon Societies, the American Nature Association, the Isaac Walton League, the American Forestry Association, and others. Perhaps your community or state has a branch. What do you know of their work?

Many wild animals need protection because their habitats have been destroyed. Some have characteristics that make them "easy marks" for the hunter. Bisons live in herds. Migrating birds may be shot in flocks. Some fish are killed in large numbers during migration. Wise conservation policies are aiding in the protection of wild animals.

Can You Answer these Questions?

1. Why does the life of man depend to a great extent upon animals?

2. Why do wild animals need the protection of man?

3. What are some of the ways in which man has exploited wild-animal life?

4. How have the natural habits of seals helped to provide a means for catching them?

5. How have the natural habits of the salmon been exploited by man to his own benefit?

6. What effect has the destroying of forests had upon wild-animal life?

7. Why were so many countries interested in the Pribilof sealing grounds?

8. Why was the passenger pigeon destroyed, while the mourning dove still exists?

Questions for Discussion

1. Should wild animals be preserved in national parks like Yellowstone Park in Wyoming or the Carl Akeley Park in Africa, even when these animals are of no possible economic value?

2. How does the wild-animal life of your region today differ from what it was a generation ago? Consider birds as well as ground life. Perhaps some older people at home can help.

3. Could the region of the Yellowstone National Park before it was settled have supported as many bears as now live there?

4. What are landlocked salmon, and how did they get their name?

Here are Some Things You May Want to Do

1. Read in class some descriptions of pigeon-trapping, bison-hunting, whaling, or other forms of sport or industry which were written before the twentieth century. See if you can find any differences in the point of view with which these things were considered by the community and the individual.

2. Look up the migratory-bird treaty with Canada and report on it in class.

3. Look up the game laws in your state and be ready to discuss such questions as Are any animals listed as having no open season? Are the seasons on most animals long or short? Are there closed seasons on the female and not on the male? See if you can explain why some of the laws you find are necessary.

4. Make a special study of the whaling industry and find out whether there is any danger that whales will become extinct. You may wish to carry this study into other fields and find out what animals have become extinct within the last century.

5. Make a special study of the migratory habits of some other fish, such as shad. Compare them with the salmon.

Chapter VIII · How have we attempted to control the Spread of Undesirable Plants?

Should you like a flower garden that requires little care; that needs no watering, no fertilizing, no weeding; one in which the plants will grow whether it rains or shines? Then be content to raise dandelions, English daisies, black-eyed Susans, Queen Anne's lace, and goldenrod.

A. What are Weeds?

A weed grows unwanted

Whether you have lived all your life in a large city or whether you have lived in the country, you are familiar with that large group of plants commonly called weeds. A weed is a plant that grows where it is not wanted and usually where we do want other plants that are more useful to us. On that account all of us who have gardens, no matter what their size, are faced continuously with the problem of getting rid of weeds.

It may seem unnecessary to name or even to describe these most common of plants. Yet many of us who see them every day have never stopped to think about them. Why are they weeds? What characteristics have they that make them undesirable?

Weeds are likely to have many seeds

Let us consider the dandelion. Is Fig. 83 familiar? Here it is summer, and those dandelion plants in our lawn have been blossoming since early April. We have mowed the lawn, — yes, many times, — but the little yellow blooms continue to appear down there tight to the ground, out of reach of the sharp knife blades. They have bloomed and gone to seed, and their white tops have blown away upon the wind. A count was once made that showed that one particular dandelion plant produced three hundred and fifty-three blossoms in one season. Did our roses, our peonies, or even our petunias

Fig. 83. The Dandelion is One of our Most Common Weeds

Notice in *A* how the leaves are spread to the sunlight, and consider what happens to grass underneath. See how the thick, sturdy taproot in *B* helps the plant to live. Is *C* a familiar scene?

do as well as that? Not at all! Did our rose seeds or our peony seeds drift away on the wind to produce new plants next season? In most cases their seeds did not even develop! Even the petunia seeds could do no better than sift into the ground about the parent plants.

Notice the leaves of the dandelion in Fig. 83, *A*. See how they are arranged in a little rosette, or cluster. There are twenty or more of them. Yet each one has found a place in the sun. Each one is a food factory in which carbohydrates are made during every sunlit hour. And notice how

Fig. 84. The Dandelion is not the Only Common Weed

How many of these weeds grow in your neighborhood? Are there any others more common, which you would want to add?

they would spread over grass beneath them. What chance has grass below this thick green mat of leaves? Now suppose we try to pull up a dandelion by its roots. You can't, you say. You have tried it? Well, dig one out with a trowel. Note the length of the thick taproot, as shown in Fig. 83, *B*. Note its strength. Compare it with the roots of a petunia, a geranium, or a coleus. Do you see why it continues to live even though the whole top may be cut off? It may also live through the winter cold and produce blooms early next spring.

Leaves of many weeds grow as rosettes close to the ground

Let us look about the lawn for other weeds. There are other kinds of rosettes. Here is plantain, both the wide-leaf and the narrow-leaf varieties. Plantains too have tough roots and many of them. Mustard, mullein, dock thistles, wild carrot, and many others reward our search (see Fig. 84). Not a very well-kept lawn, you think? Carefully look over your own lawn, with an eye to rosettes that spread in the sunshine and roots that cling tightly to the soil.

Weeds are likely to have tough roots

Give a thought to the seeds of these plants. Are they many? Are they easily transported? Are they hardy?

One scientist tells us of some work in counting weed seeds. A single average-sized pursley plant produced 69,000 seeds. A rosette of Queen Anne's lace produced 50,000, and a mustard plant produced 1,500,000. He tells us of further observations where weed seeds have lived dormant in the ground for as long as thirty years and then sprouted when conditions became more favorable.

There is still another important reason why many weeds have made themselves so objectionable. You know that a plant in its native environment is likely to have many natural enemies. There are insects, fungus growths, birds that eat its seeds, and other things which prevent it from spreading. Some of our worst weeds are *not* native. They have been brought here for one reason or another, found the environment satisfactory, spread rapidly, and had few or no enemies to stop them. Dandelions, daisies, sorrel, pursley, wild onion, pigweed, mustard, plantain, mullein, dock, and thistles are a few of the weeds that have been imported. Some, at the time they were brought here, were considered useful as medicines or spring tonics, some as "garden greens," and a few as additions to the flower garden.

Many weeds are imports and have few enemies except man

You may be interested in a number of plants, imported more recently, that seem to be in a fair way to become

pests. During the World War foxglove, or digitalis, used as a medicine for the heart, was raised in gardens in this country because it could not be imported. It has beautiful tall spikes of blue blossoms. In several localities it has proved much too well adapted to its new environment and has escaped into the fields.

You have read about the red poppies which grow in Flanders fields. They have become an emblem of the World War veterans. These beautiful flowers, a pest in Flanders wheat fields, have been introduced to us recently in wheat seed. Will they become a pest in America?

The Russian "thistle" has lately been introduced in flaxseed from Russia. It has become most undesirable in the eyes of Western farmers.

Thick in the waters of Florida ponds and streams, as shown in Fig. 85, is the beautiful water hyacinth, known among the natives there as "lilac devil." You who live in Northern cities may pay a quarter apiece or even more for these plants when you buy them for your aquariums. But Florida would be very glad to get rid of them all.

Some weeds are poisonous and produce unpleasant results

You may ask why weeds are harmful. The chief reason is that they take the place of other plants of greater value. But there are other reasons as well. Take the case of the wild onion which may grow in wheat fields. Just a very few onion seeds ground with the wheat will make the flour unfit for use. Daisies and dandelions dried in hay and fed to cows produce bitter milk. A little wild onion in the cows' diet results in milk that smells like garlic. Other weeds in the fields are poisonous or even deadly to cattle, sheep, and horses. Among these are low laurel, water hemlock, dogbane, nightshade, pokeweed, and loco weed. Some of these are shown in Fig. 86.

Weeds damage the growing plants by robbing the soil of nitrogen and other chemical elements necessary for plant growth. They are damaging also because of the

Ewing Galloway

FIG. 85. Owing to their Rapid and Wide Growth Some Weeds cause Much Difficulty

The picture shows a Florida stream choked with water hyacinth, or "lilac devil"

water they take from the soil. The leaf surface of a morning-glory vine, for example, is enormous. There are millions of stomata on the undersurface of the leaves, and through each of these small openings there is a continuous flow of water. It may require as much water for growth of a morning-glory as for growth of a corn plant. In case of drought this is extremely important.

Poison ivy and poison sumac are poisonous to the touch as well as to the taste and may cause severe skin infections. If you do not already know them, you should learn to recognize these plants and to keep at a safe distance from

Fig. 86. Some Weeds are Poisonous to Animal Life

Are any of these common to your region? What steps are being taken to get rid of them?

them. The poison in the case of these pests is in the form of a heavy oil which comes from the leaves and stems. This oil may turn to vapor, and persons especially susceptible may be poisoned as they pass along a road where ivy or sumac is being burned or mowed. Fig. 87 shows some poison ivy beside its harmless relative the Virginia creeper.

Two other weeds, giant ragweed and lesser ragweed, or wormwood, are believed to be the cause of most cases of hay fever. The pollen from these flowers is carried by the wind, and to sufferers of hay fever it is extremely irritating to the mucous membranes in the eyes, nose, and throat.

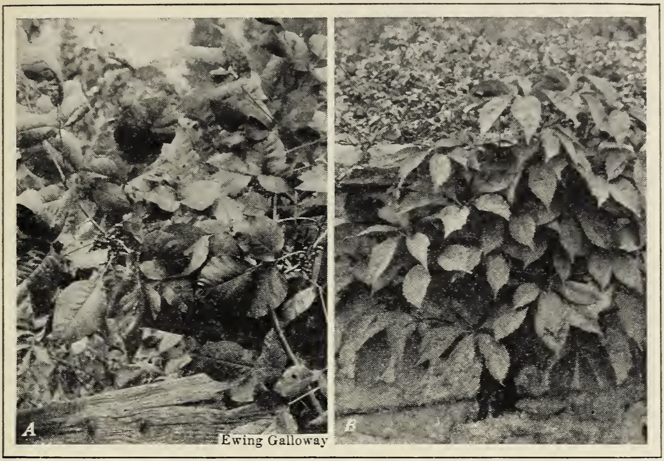


Fig. 87. Poison Ivy is really Poisonous to Many People. Virginia Creeper is Harmless

You should be able to recognize these two plants. *A*, the ivy; *B*, the creeper

B. How do we control Weeds?

By understanding the nature and habits of our worst weeds we may be able to get rid of them. Without this knowledge our warfare against them is ineffective.

Control depends upon understanding the habits

Let us take dandelions again as an illustration. You go out on your lawn to dig them. You should do this very early in the spring before the first seeds have ripened and blown away. You should be sure that you are using a tool which reaches the roots; for, if not, the roots will soon sprout, living meanwhile on the food that is stored in them. And after you have dug them, be sure you carry them away and destroy them. If you don't, they may take root and grow again. If there are so many plants that you cannot dig them, another method is to stab each rosette in the middle with a sharp stick dipped in carbolic acid or sulfuric acid.

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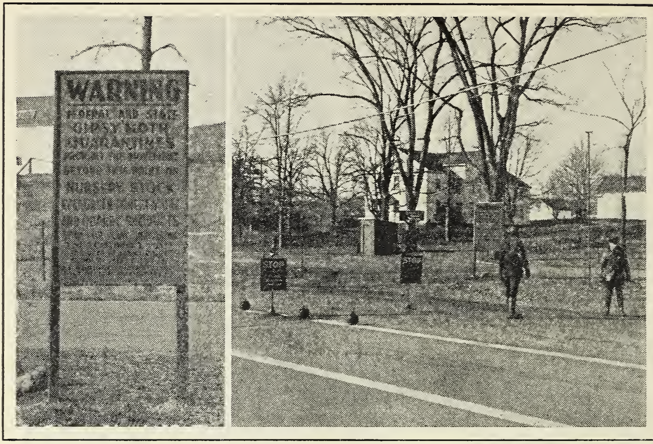


United States Department of Agriculture

Fig. 88. The Government, through Strict Quarantine Laws, forbids the Transportation of Some Undesirable Plant Pests from One Region of the Country to Another

These chemicals are strong enough to kill even dandelions. Other rosettes in your lawn may be dug or poisoned in the same way. But if the lawn is too bad, it should be dug up, rolled, and reseeded. In so far as possible the grass seed should be free from weed seeds. But most grass seed contains weed seeds. In good-quality seed sold by reliable companies as many as sixty thousand weed seeds per pound have been counted.

As for keeping the weeds out of a garden there seems to be only one way. Just keep on pulling them and hoeing them out. It is especially important of course to get rid of them before they are old enough to flower, so that no seeds may be formed. It is also important that they be placed where the roots have no possible chance of coming in contact with the soil again. For this reason it is better to weed a garden during hot, dry weather than when the soil is wet.

When a farmer's hayfields become badly invaded by weeds, he has little choice except to mow the land early before seeds can form and then to plow the entire area. It should be cultivated for one or two seasons, after which grass may be resown.

If the land is well fertilized and good seed sown, the grass will get a start before the weeds do. Grass needs soil rich in phosphates, potash, and nitrates. Weeds grow best in an alkaline soil. An excellent lawn fertilizer used according to directions is ammonium sulfate. This chemical is slightly acid. Being acid, it encourages grass while it discourages the growth of most weeds. Fall seeding for grass or hay is best.

The United States has certain quarantine laws that forbid the entrance of uninspected plants into the country and that also forbid the transportation of plants from one part of the country to another. Perhaps you have seen a sign such as the one in Fig. 88.

C. How do we control Fungus Diseases of Plants?

There are other kinds of plants still more undesirable than weeds; but because many of them are so small that they can be seen only through a microscope, one is perhaps less likely to think of them. We refer to the group of fungi known as rusts, smuts, and blisters.

Let us tell you briefly about four of them that are typical: the white-pine blister, the wheat rust, Dutch elm disease, and the chestnut-tree blight.

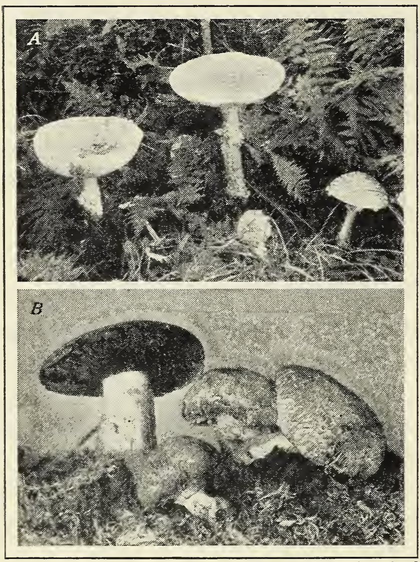
Fungi must live upon other plants

Fungi are flowerless plants that produce others of their kind by means of dustlike particles called spores. A fungus has only one parent. Fungi are not green. They contain none of the coloring matter (chlorophyll) which makes it possible for a plant to make its own food. Consequently these fungi must live upon food produced by other plants. Some of them live upon dead

things; among these (Fig. 89) are mushrooms, toadstools, and molds. They are called saprophytes. Others live upon living things. They are called parasites. Examples of parasites are the rusts that live upon larger living plants.

Wheat rust lives on barberries part of the time

Rusts produce spores which look somewhat like iron rust. They pass through several different stages in their life history. Indeed as many as five different kinds of spores may be borne by a single rust. The growth of wheat rust begins in the spring, when tiny cuplike organs filled with spores appear on the underside of the leaves of the common English barberry bushes. These spores, which grow only upon barberry bushes, are blown through the air; some of them fall upon wheat plants. Soon reddish spores appear upon the wheat. They may spread to other wheat. Later in the season black spores form on the wheat stalks, where they remain dormant until early spring. At that time the spores are blown from the wheat to the barberries, and another life cycle similar to that in Fig. 90 begins. The rust feeds upon chlorophyll and so is very damaging to the wheat.



J. Horace McFarland

Fig. 89. Fungi live upon Food produced by Other Plants

A, toadstools; *B*, mushrooms. One is poisonous as a food; the other is not. Can you tell them apart?

FIG. 90. Wheat Rust is a Parasite

At the top, the spores on the underside of English barberry leaves; at the right, the first signs of the rust upon a healthy wheat plant; at the left, the result of the rust. How may this parasite be controlled?

There are two chief means of keeping the wheat rust under control. One is to find wheat plants that can resist, or are immune to, the attacks of the rust. When such plants are found, new varieties can be developed from them in accordance with the laws discussed in Chapter II. Several varieties are raised at the present time that are able partially, but not wholly, to resist rust. The Marquis is one of them. Another method of control is to do away with all the barberry bushes in the country. This does not include the Japanese barberry commonly used for hedges, but only the wild barberry originally introduced from Europe, whose berries your mothers or grandmothers may have used for making sauce.

A method of control is to do away with the barberries

For centuries there was a saying among European peasants that barberry bushes near a wheat field would spoil

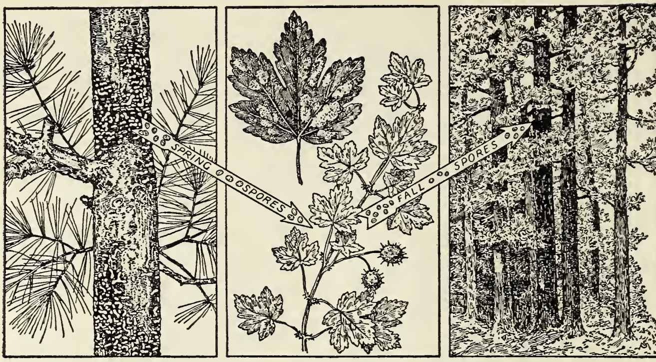


Fig. 91. White-Pine Blister is Another Form of Parasite

The English black-currant bush serves as host part of the year

their wheat. Some people said it was only a superstition, but they were wrong. In this case a correct relationship was observed long before it was explained.

The white-pine blister is a fungus that attacks white pines. It never grows upon red pines or yellow pines, always upon some variety of white pine. Just how it was introduced into this country no one knows, but it appears to have come from Europe early in the twentieth century. It spread rapidly through the pines of New England and New York, and experts of the Department of Agriculture began to study it.

White-pine blister is controlled by destroying currant bushes

They discovered that this fungus lives part of its life upon the white pine, but the rest of its life upon currants or gooseberry bushes. It grows especially upon the English black currant. The cycle is shown in Fig. 91. The control in this case is by destroying all currant and gooseberry bushes, including wild ones that may be growing in the woods. This the state foresters proceeded to do through large sections of the country, much to the disgust of housewives who liked to make currant jelly and gooseberry tarts.

C. F. Korstian, United States Forest Service

FIG. 92. There are Other Forms of Fungus Diseases

This shows the destructive action of the chestnut blight. *A*, enlargement of the branch and splitting of the bark. *B* shows numerous threads of material in which immense numbers of spores are found

But it was a question of losing the currants or losing the pine trees. Which do you think is more important?

The Dutch elm disease is a blight which has only recently appeared upon elms in New Jersey and adjoining sections of New York. It grows just under the bark of the tree and may be identified as a thin brown streak. It is believed to have come to us from Asia, but by way of Holland, where it was noticed as long ago as 1919.

The Dutch elm fungus is carried by a beetle

It is not known that this elm fungus lives upon any other plant, but experts are now fairly certain that it is carried from tree to tree by a hard-shelled brown beetle a little less than a quarter of an inch in length. It is called the European

elm-bark beetle. The adult beetles carry spores upon their bodies from infected trees to healthy ones. Whether they have any closer connection with the disease is not yet known. The only way to prevent their rapid spread seems to be in burning all trees that are found to be infected.

Scarcely a generation ago boys and girls who lived near the country spent many delightful autumn hours gathering chestnuts and eating them or perhaps taking them home and roasting them. But a modern youth looks at us in astonishment when we tell him about chestnuts. Eat them? He knows only horse-chestnuts! Or possibly, if he lives in the larger cities, he knows the huge Italian chestnuts sold at sidewalk peanut stands. These are imported. Our eating chestnuts have nearly vanished, the victims of a bark fungus brought into this country from northern China.

The chestnut-tree blight has destroyed our native eating chestnuts

This little fungus finds a foothold on the inner bark of the chestnut tree and sends out rootlike projections in all directions. Upon the outer bark there soon appear little cups filled with spores. These spores stick to the feet of birds and insects and may be carried long distances. Other spores may be carried by the wind. No way has been discovered to stop the progress of the chestnut-tree blight. Since 1904, when it was first discovered in a park in New York City, it has spread through nearly all the chestnut trees in the country. Even more recently, in the summer of 1934, there has appeared upon the horse chestnuts in the Eastern states a blight of some sort that appears to be killing them too.

D. How do we control Bacteria?

A chapter on undesirable plants would certainly be incomplete without some mention of bacteria. You know something about these and will learn more later. It is true that only a few kinds of bacteria are harmful, and it is

true that you will study these organisms at much greater length at a later time. Nevertheless they are in some important instances our most undesirable members of the plant kingdom.

Some bacteria make or enrich soil

A bacterium is a one-celled plant so small that it can be seen only through a microscope. It belongs to the fungi, so it cannot manufacture food. Therefore bacteria must live upon other organisms. Some kinds of bacteria live upon dead plants or animals, and in so doing cause them to decay. If it were not for such bacteria, the world would be covered with dead branches, roots, and dead bodies. The bacteria use these dead things for food and in the process make their chemical elements again ready for use by other living things. Other bacteria, using nitrogen from the air, produce nitrites and nitrates that are used by larger plants. Without bacteria it is difficult to see how the larger plants could grow.

Most bacteria are neither helpful nor harmful. Some cause disease

Most kinds of bacteria are neither helpful nor harmful; and since they are also invisible, they are of little concern to us. But some are decidedly harmful. It is a bacterium that causes diphtheria, another bacterium that causes typhoid fever, and still another that causes lockjaw. Two or three different kinds of bacteria are known which cause pneumonia, while still smaller organisms are suspected in the cases of smallpox, scarlet fever, and influenza.

Bacteria are unlike the larger plants in many respects. In the first place, they produce another generation simply by dividing, and they do this very rapidly. A single bacterium living on the proper food and at proper temperature may have multiplied into a million in two or three days.

Bacteria need certain conditions in order to grow rapidly. One, as in the case of other organisms, is food; a second is moisture; a third is moderate temperature. But the fourth may surprise you; it is darkness. Sunlight destroys bacteria.

Knowing these facts, the control of harmful bacteria becomes easier. But of this you will learn more in a later chapter.

Undesirable plants are weeds, some fungi, and some bacteria. Weeds are plants that grow where they are not wanted. They are especially well adapted to their environment usually producing many seeds. They may have long roots, rosette leaves, or other characteristics that fit them to win in the struggle for existence. We control them by understanding their habits of living. Fungi live upon food made by other plants. Some have two host plants. By getting rid of one host we may destroy the fungi. Most bacteria are not harmful. A few are especially dangerous. These too are controlled by understanding their methods of living.

Can You Answer these Questions?

1. What is a weed?
2. Why is it so difficult to get rid of the dandelions in a lawn?
3. What are some of the ways in which undesirable weeds have been introduced into this country?
4. Why are weeds undesirable on a lawn?
5. What are some of the methods by which weeds may be controlled?
6. Which is generally the more favorable for weed growth, alkaline soil or acid soil?
7. What are fungi?
8. State the difference between a parasite and a saprophyte.
9. What is meant by plant rusts and blisters?
10. What are the life cycles of some plant diseases such as wheat rust or white-pine blister?
11. How are bacteria like fungi?
12. What is a secondary host?
13. What damage is done by weeds in a cultivated field?

Questions for Discussion

1. Why, if weeds produce as many seeds as this chapter indicates, is not the world overrun with weeds?

2. Are weeds of any use at all?

3. Is the government justified, in order to protect your neighbors' white-pine trees, in destroying currant and gooseberry bushes on your property when you are perfectly satisfied to have them there for the fruit they produce?

4. Why do you think that weeds often grow so much better than cultivated plants?

5. How are some kinds of bacteria helpful to man?

Here are Some Things You May Want to Do

1. Make a collection of weeds from your own garden or school lawn. Study their habits and explain why they are weeds. Perhaps you would rather collect the seeds from some common weeds.

2. Are there any plant quarantine laws in your state? Why were they set up? How are they enforced? To what extent have they saved you money? Make a study of these laws and report on them in class.

3. Many common weeds have peculiar names, such as the loco weed, pokeweed, dogbane, and nightshade. See if you can find out where these names had their origin.

4. In De Kruif's *Hunger Fighters* you will find that Chapters I and II deal with the story of the fight for a rustproof wheat. If you want the same story in equally interesting form, see if your library has Cannon's *Red Rust*.

5. Make a study of some fungus growths in your community. See if you can trace the life cycle of some common forms.

6. Make a study of the ways in which the seeds of ten common weeds of your community are spread.

7. Read Lutz's book *The Fly-Aways and Other Seed Travellers*.

8. Spread grass seed on a glass plate and with a hand lens search for seeds that are not grass. How do you think they got there?

9. What activities directed toward control of fungus diseases have been carried on in your community during the past five years?

Chapter IX · How are the Activities of Insects related to the Activities of Man?

"The War of the Insects," "Will Insects starve us to Death?" "Combating Garden Pests," "Parasite destroys Jap Beetle," "Civic Groups join Forces to exterminate Mosquito." Similar headlines are familiar in all our newspapers and magazines. Do they not picture our attitude toward the insect world?

Fig. 93. In the Past Some Insects, Such as the Scarab Beetle of Egypt, have been considered Sacred[1]

Do you know why?

Probably you have read of the sacred scarab beetle of Egypt (Fig. 93), the mantis that is worshiped in India, or the locusts that are caged as pets in the Orient. Two other insects, the silkworm and the honeybee, are most carefully protected. Indeed these two insects might very properly be described as domesticated animals.

Are insects useful or injurious? What is the truth as to the place of insects in our scheme of things? It is certain that we do not feel toward insects as we do toward most other members of the animal world. What habits of theirs make them desirable or undesirable? Let us see if an unobjectionable insect may in a short time become most undesirable.

[1] From Linville, Kelley, and Van Cleave's *General Zoology.*

A. What Insects are Especially Useful?

An insect is a six-legged animal possessing a jointed body and a hard outer skeleton. Most of them are small in comparison to the higher orders in the animal world. There are more insects than all other members of the animal world put together. There are even more different kinds of insects than all the kinds of other animals.

Nearly all insects pass through four different stages in their life history, beginning with an egg and ending with an adult. During at least one stage they are tremendous eaters. Since many of them live upon plants that we need for purposes of our own, we class them as pests or nuisances. A few insects, however, have characteristics that make them useful.

Let us consider the silkworm, which since ancient times has been domesticated in the Orient. The silkworm hatches from an egg. When it comes out, it is scarcely larger than this letter *s*. It is one of about a hundred caterpillars that are hatched from the eggs of one mother. The eggs of these tiny caterpillars, commonly but incorrectly called worms, are laid upon the leaves of a mulberry tree. As soon as the caterpillars hatch, they begin to feed upon mulberry leaves, and eat several times their own weight each day.

The silkworm lives on mulberry leaves

Within a few days the hard outer covering, or exoskeleton, of the tiny creature becomes too small for it, and the caterpillar crawls out, leaving its skeleton, or "skin," behind. It has another skin underneath, however, which hardens as soon as it is exposed to the air. The caterpillar now resumes eating, a process which continues until again it is too large for its skin. It sheds its skin four or five times. Between each of these shedding periods it eats until it can hold no more.

Finally, when the caterpillar is about an inch and a half long and not quite as big round as a pencil, it stops eating.

It now begins to spin from its mouth a fine cream-colored silk thread. This it wraps round and round its body until it is completely covered. The caterpillar inside the cocoon, as this silk covering is called, now sheds its last skin, which you may find inside a cocoon if you open one. The queer, quiet, brown thing that remains under the last caterpillar skin is called a pupa. This pupa seems to have no legs, eyes, or mouth. It remains within the cocoon for about two weeks.

The silkworm spins a silken cocoon in which to live through the pupa stage

At the end of this time, if left undisturbed, the cocoon begins to move, to roll from side to side. From one end a wet insect appears. It has a large body and four small, soft, creamy wings. Clinging to a leaf or other object, the insect begins exercising its wings. By the end of half an hour they are dry and expanded. You recognize a rather pretty white moth, not as pretty, however, as our own larger native moths. You have thus followed the silkworm through four stages in its life — egg, caterpillar (or larva), pupa (in the cocoon), and adult moth. Some of these stages are shown in Fig. 94. If the adult moth is a female, she soon lays eggs upon more mulberry leaves. The life cycle is then repeated. Nor does she fail in her instinct to lay her eggs upon mulberry leaves, for this is the only kind of food that her young offspring will eat.

All other moths and butterflies pass through these same four stages in their life history, the caterpillars eating many times their own weight of their particular kind of food. Flies, beetles, bees, and wasps pass through similar stages. Insects that live through the four steps of egg, larva, pupa, and adult are said to have complete metamorphosis. *Metamorphosis* means "change in shape."

But let us see how man interferes in the life of the silkworm. The silk cocoon is the source of silk thread and silk cloth. When it is spun into a cocoon by the caterpillar, it is all in one long thread; but after the moth chews its

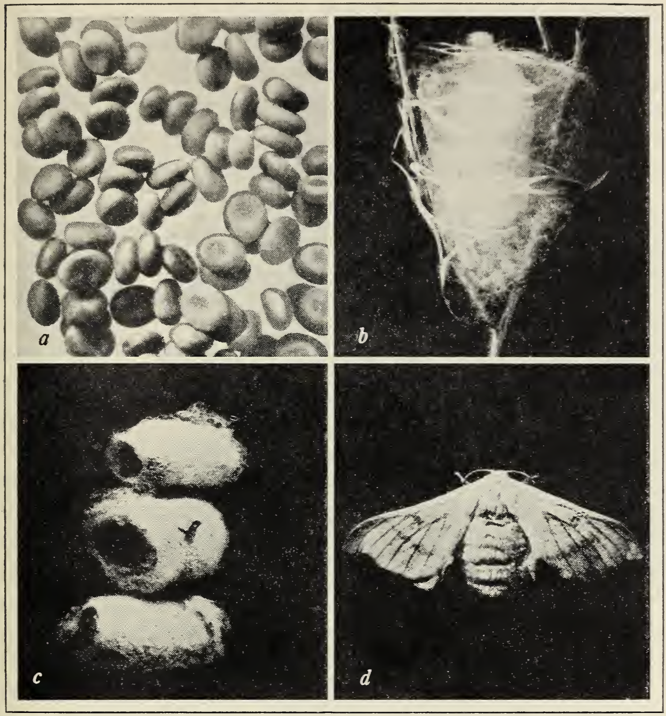


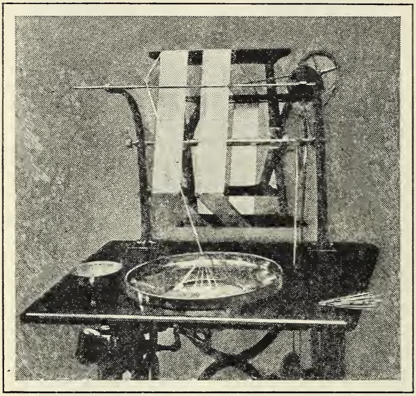
FIG. 94. **Some Insects, such as the Silkworm, have Characteristics which make them Useful**

a, the egg (enlarged); *b*, the pupa (in the cocoon); *c*, the cocoon after the moth has come out; *d*, the adult moth. Which stage of metamorphosis is missing here?

way out, the thread has been broken at every turn. Consequently the time to collect the silk for use is before the moth comes out.

Accordingly, at this stage attendants who have cared carefully for the caterpillars, feeding them fresh mulberry leaves many times a day, collect the newly made cocoons and plunge them into boiling water. This kills the pupæ, and the silk is unwound in a single thread (Fig. 95).

Although silkworms are not found wild today in any part of the world, it is certain that they had their origin somewhere in the Orient. They were introduced into Europe during the Middle Ages, and the silkworm industry became an important one in France. During the nineteenth century attempts were made to raise silkworms in several parts of the United States, and mulberry trees were planted in large numbers. But the industry did not flourish. Although both the mulberry trees and the worms seemed well enough adapted to the new environment, our people were unwilling to work for the small profits made by silkworm attendants in France and the Orient.



© Monotuck Silk Company

Fig. 95. The Normal Life Cycle of the Silkworm must be interrupted if Silk is to be Secured

The picture shows a machine unwinding the cocoon

The honeybee is another insect that is useful to man. It is important because of the honey that it produces and also because of its part in the fertilization of many flowers.

The honeybee makes honey and cross-fertilizes many flowers. Both characteristics are desirable

You know how bees carry pollen from flower to flower, thus aiding unconsciously in cross-pollinating and cross-fertilizing them. The bees, along with other insects, play a part in producing apples, peas, beans, and other food products, but our concern here is with bees as makers of honey.

Honey is a substance made by worker bees from the nectar of flowers. Nectar itself is the sweet liquid contained

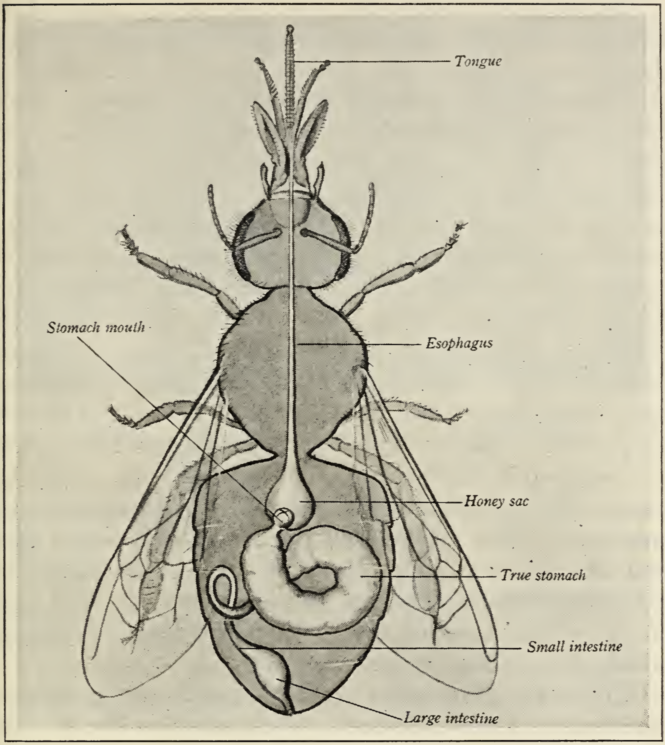


FIG. 96. Honey is produced as Nectar is sucked into the Stomach, or Crop, of the Worker Bee and partly digested There

in flowers, especially in buckwheat, clover, alfalfa, mustard, orange blossoms, and palms. Nectar is sucked into the honey sac, or crop, of the worker bee and partially digested there. Perhaps Fig. 96 will help you to understand the process. Honey is made from nectar in the honey sac. Enough passes into the true stomach to supply her need for food. The worker then disgorges, or gives up again, the part she does not need for her own food. This honey is food for the queen bee and for the young bees, or larvæ.

T

But we must describe the work and the occupants of the beehive; for bees, as you know, live in colonies, dividing duties among themselves. Most important is the queen bee. All the activities of the hive center about her, for she is the mother of all the other members. Her sole business in life is to lay eggs, and during the height of the honey-making season she may lay as many as ten thousand in one day. A hive may contain twenty-five thousand adult members at one time or even many more when beekeepers interfere with nature. A few members of the hive are adult males, or drones. There is one queen. The rest of the colony is made up of worker bees. These workers are females but smaller than the queen and incapable of laying eggs. They are believed to be unlike the queen only because they were fed upon different food when young. The workers are assigned to various tasks within the hive. Some are nurses who feed and care for the young. Others patrol the entrance in order to keep out intruders. Still others clean and ventilate the hive. Many of them spend their lives gathering nectar and pollen. While a queen may live to be three or four years old, the workers are worn out and die within four or five weeks in summer.

Within the hive is the comb — many cells of beeswax built in layers, one upon the other, as shown in Fig. 97. The queen lays eggs, one egg to a cell. In other cells, workers store food — pollen, or beebread, for the youngest grubs, as bees are called in the larva stage, and honey for the older ones. The wax itself is a substance that is discharged from glands in the bodies of the workers. This wax may be used again and again by several generations of bees.

The cells in which the queen lays her eggs are always near the bottom of the hive, while food is stored in the upper stories. Because of this fact man has found it possible to take honey from the bees and use it for himself without disturbing grubs and young bees.

Honey was the only sugar, except that in ripe fruits,

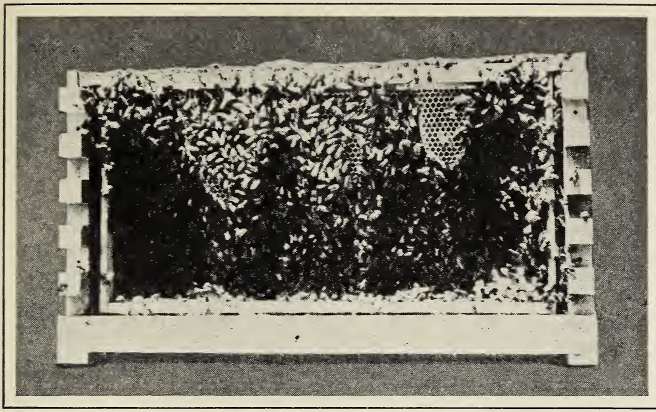


FIG. 97. Honeycomb is Many Cells made of Beeswax
Honey is stored in the cells for future use

which was known in Europe before the sixteenth century. The American Indians had maple sugar and cactus sugar. The people of the Orient had cane sugar, but the Europeans had only honey. Many are the references to honey and praises of it in ancient and medieval literature.

Chemically, honey consists of three different sugars — sucrose, dextrose, and levulose. In addition there are small amounts of mineral substances and sweet oils. A mixture of dextrose and levulose is commonly called glucose.

Until recently, when a man found a hollow tree in which there was a swarm of honeybees, he marked it with his initials. Later, at his own convenience, he went back and "smoked out" the bees. In this process a fire was built beneath the nest so that smoke from the fire either killed the bees or caused them to fly away. The finder then took the honey from the hive. Obviously such a method was destructive and wasteful.

A modern beekeeper provides boxes for the bees instead of the hollow trees used by wild bees. He provides upper layers that can be removed easily. He thus takes advantage

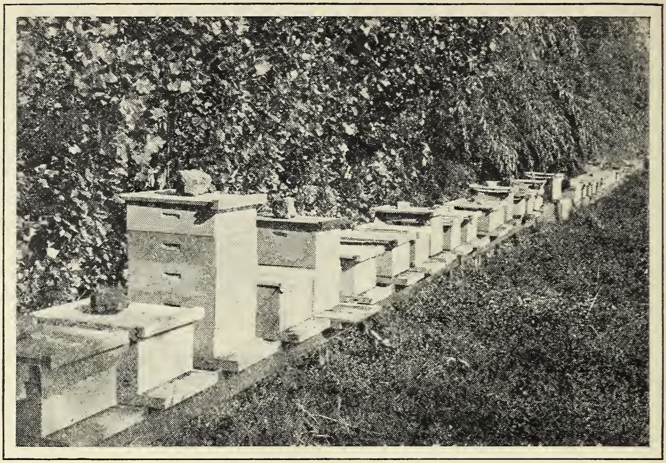


Fig. 98. A Modern Beekeeper provides Boxes for the Bees, in which they can build their Comb and deposit Honey

of the bees by removing some of the honey that they have made for their own use, but he does not kill the bees. And he is careful not to remove all the honey, for he knows that they need some of it. Some modern hives are shown in Fig. 98.

We have given you full descriptions of the silkworm and the honeybee in order to show how man has benefited by taking advantage of certain natural characteristics of insects. Because a caterpillar spins a warm cocoon for itself, man has silk. Because a colony of worker bees must provide carbohydrate food for young grubs, man has honey.

Some insects are useful because they are parasites on other insects

Nor are these the only insects that are useful to us. There are many insects which feed upon other insects that damage crops and gardens. There is, for instance, the common ladybug, or ladybird beetle. This little red beetle with the black spots never eats plants. Its diet is composed almost exclusively of aphids and scale insects. Therefore, if you should find your house plants or tender

garden plants covered with plant lice, one of the best ways to get rid of them would be to get a supply of ladybugs to eat them. Nor would this be difficult, for ladybird beetles are raised and sold for that very purpose. If the ladybug is not already familiar to you, you should learn right now to recognize it (Fig. 99). Probably it is common in your own garden.

The dragon fly, or "devil's darning needle," has gained a bad reputation among boys and girls who have been told that it will sew up their mouths. Certainly in this case reputation and true character are directly opposite. The dragon fly is a "dragon" only in its dealings with mosquitoes, and it could not possibly sew anything.

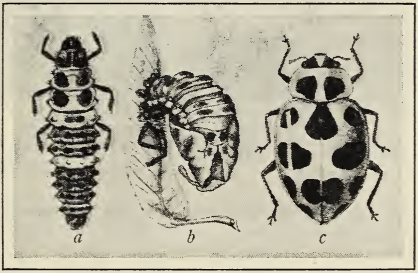


Fig. 99. Some Insects, such as the Ladybug, are Useful because they Prey on Other Insects

a, larva; *b*, pupa; *c*, adult

The young dragon fly hatches from an egg laid on pond or swamp vegetation. It develops into a fierce-looking insect with big head and strong legs but no wings. And indeed it is fierce in its attacks upon mosquito larvæ or other small water creatures. After a few weeks the young "dragon" has eaten enough. It crawls up out of the water and rests itself on a stem of grass. Soon its shell, or skin (exoskeleton), splits near the head. The insect crawls out. See its beautiful wings and long slender body. It is now an adult; the rest of its life is spent in the air, darting about in search of insects that it may eat. The dragon fly, you see, is helpful rather than harmful, in so far as man is concerned.

You should notice that the life cycle of the dragon fly includes only three stages: (1) egg; (2) young without

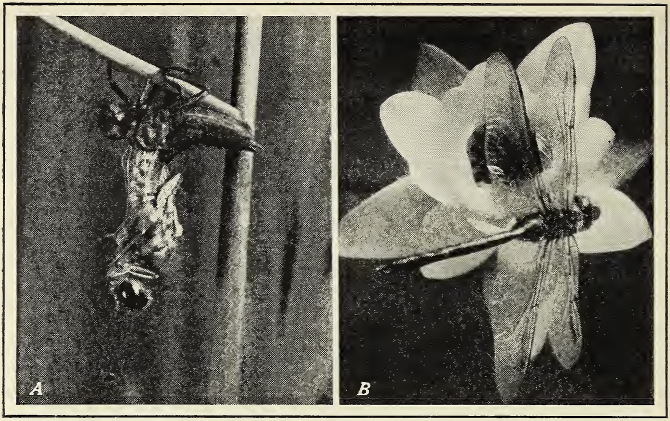


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Fig. 100. The Dragon Fly is an Insect which is said to have Incomplete Metamorphosis

A, coming out from pupa case; *B*, adult. Which stage is missing?

wings, or nymph; (3) adult. Two of these are shown in Fig. 100. Grasshoppers, damsel flies, locusts, walking sticks, mantes, and a few others pass through three similar stages. These insects are said to have incomplete metamorphosis.

Another insect that is especially useful is the praying mantis. This is not a native insect, but is believed to have been introduced with a shipment of Chinese nursery stock near Philadelphia at about the end of the nineteenth century. The mantis, as you may know, is a creature between three and four inches long. It is brilliant green, the color of young leaves, with green or brown wings. It looks something like an overgrown grasshopper. Its value lies in the fact that it eats other insects, especially grasshoppers, beetles, and flies. It catches these with its front feet, or claws, holding them securely while it eats them.

Mantis eggs are found in frothy clusters stuck to a twig or weed stem. More than a hundred young may come from

a single cluster, or egg mass. Because the praying mantis has aided so greatly in the battle with beetles and other insects, persons in the areas where mantes are plentiful have collected egg masses and sent them to other localities to aid in keeping destructive insects in check.

Among the insects that are useful because they destroy other insects come that large group known as parasites. Some parasites lay their eggs in such a way that other insects become their hosts or their victims. Fig 101 shows a picture of a tomato worm. It is the caterpillar of the large gray hawk moth and is ready to pupate, or make its cocoon. This should be made underground in the soft soil, but the caterpillar seems to lack energy. It is not dead, for it still moves. All over its back you may see tiny white cocoons, perhaps a quarter of an inch long. Soon the caterpillar will die.

Fig. 101. Some Insects lay their Eggs in such a Way that Other Insects become their Hosts or their Victims

A tomato worm covered with the larvæ of the ichneumon fly

The explanation? A small fly belonging to the group called ichneumon flies laid her eggs a week ago beneath the skin of this fine large caterpillar. The eggs hatched, and the larvæ fed upon the flesh of their host. Now the larvæ, having eaten their fill, have made their cocoons. Soon they will appear as flies, and some of them will lay eggs from which will come larvæ that will destroy other caterpillars. Other varieties of ichneumon flies lay their eggs in other kinds of caterpillars and beetle grubs. Indeed there are very few insects that do not have parasites of some kind. Of course there are other insects, such as fleas and lice, that live upon people or domestic animals, and these are decidedly harmful.

A second type of intruder is found among the ants. Ants, as you know, live in communities in many ways similar to the bees, and hoard large stores of food. If you should dig into an ant hill, you might find that it contained two or three kinds of ants and perhaps a large red beetle or two. The red beetles are fed by the worker ants, even to the neglect of their rightful charges. But so far as anyone has been able to discover, the beetles do nothing at all for the ants. There may also be some very small ants that have tunneled into the hill to steal food. These too are intruders. It may even be that the queen herself does not belong to this colony, but has killed the rightful ruler and induced the workers to care for her own offspring. These various invaders help to keep in check the always too numerous ant population.

A method of control of harmful insects is suggested in this study of useful insects; and although we have not yet discussed the harmful ones, you will understand the meaning of the following statement made by the chief of the United States Bureau of Entomology:

> One way to combat insect pests which have been introduced accidentally into the United States from abroad, is to introduce deliberately the parasites and predators that keep these insects from becoming major pests in the country of their origin.

B. What are Some Especially Harmful Insects?

It depends a good deal upon which section of our country you live in and during what particular year you read this book as to which special insect you would describe as the most dangerous public enemy. Grasshoppers, European corn-borers, Japanese beetles, Colorado potato beetles, cotton-boll weevils, Mexican bean beetles, chinch bugs, house flies, mosquitoes, gypsy moths, tent caterpillars, measuring worms, cockroaches, ants, — any of them are bad enough, and there are many others. There may be a new one next year.

All these harmful insects have habits we do not like. They eat the leaves or fruit of our trees, they destroy our garden vegetables, or they live in filth (dirt and impure matter) and carry disease. According to L. O. Howard, one of our leading students of insects: "Insects are man's chief rivals for the possession of the earth. They are damaging us more today than at any time since civilization began." Most of the insects that are causing serious trouble today have been brought into the country, usually unintentionally, without their natural enemies. They have spread rapidly because there were no parasites to kill them.

Harmful insects are those having habits that interfere with ours

The story of the gypsy moth (Fig. 102) is now almost a classic. In 1869 in Medford, Massachusetts, a French astronomer was experimenting with silkworms as a hobby. He was trying to crossbreed silkworms with some little imported brown moths in order to produce a variety immune to certain diseases prevalent in France. A box of insect eggs rested on a window sill. The window was open, and, according to the story, it took but one sudden gust of wind to scatter the eggs beyond recovery.

The gypsy moth was introduced by accident

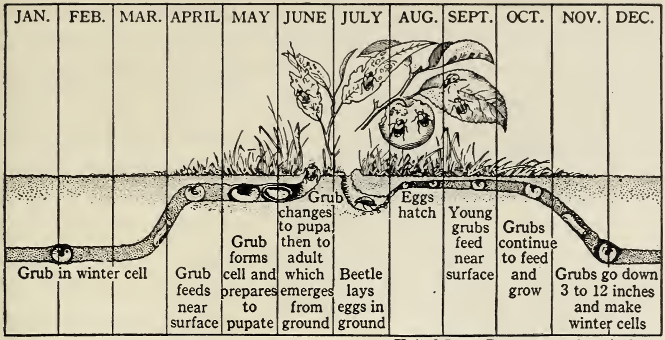
Nothing happened for a while. For nearly ten years there were not enough of these new insects to cause much damage. They passed unnoticed. Then quantities of caterpillars appeared. They cleaned the trees of leaves for miles around. Within a dozen years they had spread through New England. It was especially bad because the caterpillars were not fussy in their choice of food. Nearly all trees were acceptable. Now seven hundred thousand dollars are spent each year from state and Federal funds to stop the advance of this one insect. Spraying the trees with poisons and introducing parasites, as well as passing quarantine laws to prevent the transportation of uninspected nursery stock, have helped in the control.

Fig. 102. The Gypsy Moth has become one of our Especially Harmful Insects

a, egg cluster; *b*, single egg, enlarged; *c*, larva, or caterpillar; *d*, male pupa; *e*, female pupa; *f*, female moth; *g*, male moth

The native Colorado potato beetle spread when a new source of food appeared

The Colorado potato beetle came east as our pioneer ancestors went west. Formerly it had lived inoffensively and unnoticed upon the wild-potato vines of Colorado. Since there was never much food, there were never many beetles. But when white settlers arrived in Colorado with their cultivated potatoes, the beetles increased a thousandfold. And they spread eastward, for there were potato fields all the way back east, clear to the Atlantic Ocean. They appeared in New England about 1875. Now in this country, each year, thousands of farmer boys "pick potato



United States Department of Agriculture

Fig. 103. The Life Cycle of the Japanese Beetle shows Complete Metamorphosis

bugs" or poison them with arsenate of lead and paris green. We share each potato harvest with our unwelcome guests.

More recently the Japanese beetle was introduced in a shipment of iris roots from Japan. It was discovered and identified by a government inspector in 1916 near Riverton, New Jersey. In 1917 the beetles were numerous enough to be destructive; and it was learned that while the larvæ feed upon grass roots, destroying lawns and fields, the adult beetles eat nearly any kind of plant. Five years later the insects had spread across the Delaware River, were serious pests in the Philadelphia area, and were found on nearly all the farms in southern New Jersey. Their range covered a thousand square miles. Fifteen years later, in 1932, they had spread three hundred miles from the place of discovery.

It is very possible that the beetle is now being held in check. At least half a dozen parasites have been introduced and appear to be successful. Special poisons, mixed with an oil very attractive to the beetles, have been tried out. Even the week-end automobilist, who seems to enjoy nothing more than to fill his car with shrubs or fruits and vegetables from the country, has learned by bitter

The Japanese beetle is a very destructive newcomer

Fig. 104. The Japanese Beetle has Some Effective Enemies

This picture shows a parasitic fly laying eggs on a Japanese beetle (enlarged about two times)

experience that it pays to be sure there are no beetles in his baggage.

Fig. 103 shows clearly the life cycle of the Japanese beetle; Fig. 104 shows one of its most effective enemies. Two other beetles common in the same localities and almost equally destructive are the Asiatic beetle and the Asiatic garden beetle. Both came from Asia. Their larvæ eat grass roots. The adult Asiatic beetle feeds on flowers, especially hollyhocks and roses. The adult Asiatic garden beetle, less well known because of its night habits, burrows in the ground during the daytime, but eats the foliage of many garden plants at night. Control lies in poisoning the grubs in the ground with arsenate of lead and in finding effective parasites.

Fig. 105. The Chinch Bug, while one of the Most Destructive of the Insect Pests, can be Controlled

Read your text again to see the meaning of this picture

The chinch bug is one of the most destructive of the insect pests in the section of the United States where wheat and corn are

grown. Its life cycle is such that it lives in an immature form through part of the season during which wheat is growing and arrives at the mature form at about the time that the wheat crop is ripe. When the wheat is ripe, the corn is in a vigorous state of early growth. The immature insects feed upon the wheat; and after the wheat is ripened, they migrate to the fields of corn. Advantage is taken of this fact in controlling these pests. Fig. 105 shows one of the measures that are taken. With the plow a trench is run entirely around the field. On one edge of the trench is a line of creosote, which you may recognize as road-dressing tar. The crawling bugs will not cross this line of creosote. It serves as an effective blockade, preventing their entrance to the cornfield. When these pests are bad, the trench along which the man is walking will contain an enormous number of them. Since they will not cross the creosote, they will be moving in a direction parallel to the line. At intervals along the trench, as shown in the figure, holes are dug with a post-digger. The insects collect in these holes and are destroyed. As the insects reach the adult stage they develop wings, and then the creosote no longer serves as a protection. They may be extremely destructive to both wheat and corn as well as to some other crops.

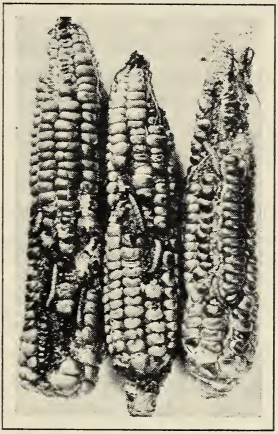


Fig. 106. The European Corn-borer can do Tremendous Damage

The European corn-borer, a moth that flies only by night, came into this country unsuspected and ruined cornfields all over New England before farmers were aware of its presence. The caterpillar that does the damage lives not upon the leaves but inside the stem of the cornstalk, often

moving upward into the cobs. Thus it leaves only a shell of a plant with sickly stalks and little or no corn (Fig.106). Government agencies are working to prevent the spread of the borer into the Western corn belt.

It would be possible of course to go on for pages, telling you how insect pests have spread and what damage they have done. Three general rules for the control of insect pests might be given in summary:

1. Keep your environment clean. Destroy rubbish in which insects may live through the winter.
2. If you discover a new pest, act promptly before it is too late. Find out what it is. Learn its habits. Then decide how best to destroy it.
3. Observe quarantine laws having to do with transportation of plants or soil that might contain insects. In a new section, where it has no parasites, an insect may be a worse pest than in its native habitat.

Insects may be helpful or harmful, depending upon whether their life habits interfere with ours. Honeybees and silkworms are especially valuable. Parasites upon other insects hold them in check. Pests break out, owing to a disturbance in the natural balance. An insect becomes a pest when natural controls fail to hold it in check. For this reason insects imported from other countries are especially dangerous.

Can You Answer these Questions?

1. What characteristics of insects make many of them harmful?
2. When does an insect become a pest?
3. Can you trace the life cycle of the silkworm?
4. What is the difference between complete metamorphosis and incomplete metamorphosis?
5. How does the sugar in honey differ from cane sugar?
6. Give examples of insects which live as parasites.
7. What factors should be considered in control of pests?

Questions for Discussion

1. What are five insect pests in your own community?

2. Have any insects been pests in your community and then later disappeared? Do you know why this happened?

3. Has the automobile helped or hindered in the control of insect pests?

4. Should you say that the production of artificial materials such as rayon has helped or hindered mankind?

5. It has been said that the beehive is a good example of organized industry. Should you agree with this?

6. Why does not honey play as important a part in the diet of man today as it did in the past?

Here are Some Things You May Want to Do

1. Make an insect collection for your school museum. Kill the insects with gasoline on cotton in a closed jar.

2. If you like to work with big numbers, you might figure out how many flies (or other insects) are produced from a single pair in a year or two.

3. Read Maeterlinck's *Life of the Bee* and Fabre's *Insect Adventures.*

4. Keep some insects in your classroom and watch them as they pass through various stages in their life history.

5. Make a special study of the life history of some one insect in which you are interested.

6. Make a chart of the common insects in your locality, indicating their characteristics as to color, size, appearance, length of season, and such other things as you think might be of value.

7. Collect cocoons of native silk moths. Keep them in a cool place outside the classroom and where they will be safe from mice. In the spring bring them in and watch the moths come out of the cocoons.

8. Make a list of six insects in your community which live through the winter in their adult stage; in the pupal stage.

Rittase

Fig. 107. Man's Progress in the Use of Materials has changed his Ways of Living and Working

UNIT III

How has Man learned to use the Materials of his Environment?

Chapter X · What has Man learned about the Use of Materials as he has progressed from the Stone Age to the Age of Power?

Chapter XI · What is the Origin of Iron, and How is it made into Steel?

Chapter XII · What determines the Usefulness of Metals?

Chapter XIII · What are the Uses of Metals Other than Iron?

Chapter XIV · What Materials Other than Metals are used in this Age of Iron and Power?

WHAT are some of the physical characteristics of our modern civilization? Think for a minute. Skyscrapers and automobiles? The radio, the telephone, the telegraph? Newspapers? Motion pictures? Streamline railroad trains? The airplane? Yes, surely all of these. You could easily add many more.

But what has brought about these things? An increasing demand for speed and comfort? The needs of a more closely knit civilization which makes it necessary for people to know within a few minutes and not days or weeks what the rest of the world is doing? The attempts of man constantly to improve himself and his ways of doing things? Yes, again, all these and many others, one of which we should like to talk about just a little since it is the story of this unit.

What is a skyscraper built of? an automobile? a radio set? a telephone? They are made of materials taken from the crust of the earth. The fine building, the powerful engine, the beautiful and finely adjusted watch,—all are made from materials that were once rock. The character of our civilization today is determined in large part by the extent of man's ability to use the materials of his environment.

In fact, as we shall try to show you, the story of man's progress through the ages is a story of his growth in ability to use materials. What do we mean? Early primitive man worked chiefly with one material, stone. Later men found use for a few metals. Within the last few hundred years, iron and steel came within the control of man. With this increased control have come many changes in human culture. Today man has gained and is gaining increased control over more and more materials. His progress is revealed by such characteristics as those mentioned in the first paragraph.

How has this control been achieved? What part has science played? What are the future possibilities? Answers to these questions are a part of the story told in this unit.

Chapter X · What has Man learned about the Use of Materials as he has progressed from the Stone Age to the Age of Power?

A. How may we learn the Story of Man's Progress in the Control and Use of Matter?

The written history of man is short

The written record of human activity goes back only a little way into the total history of man. Man has been on earth for possibly a million years, yet there is a written record of only the last six thousand years. In spite of this, much is known of man's early history. We shall limit ourselves here to considering what has been learned of man's progress in the use of those materials which form a part of his environment.

The knowledge of modern man is an accumulation of knowledge gathered through the ages

Let us study two contrasting situations. Imagine, first of all, that we have gathered in one place masses of the raw materials which go into the making of an automobile. There is a pile of iron ore. One is shown in Fig. 108 together with the mine from which it was taken. There are also quantities of other materials: charcoal, aluminum, raw rubber, and tin. Now for our first situation imagine a group of modern, highly trained engineers faced with the problem of changing these raw materials into an up-to-date motor car. Can they do it? You of course know the answer, for you see the modern motor car every day. These engineers can draw upon knowledge gathered through centuries and can produce a highly refined piece of machinery.

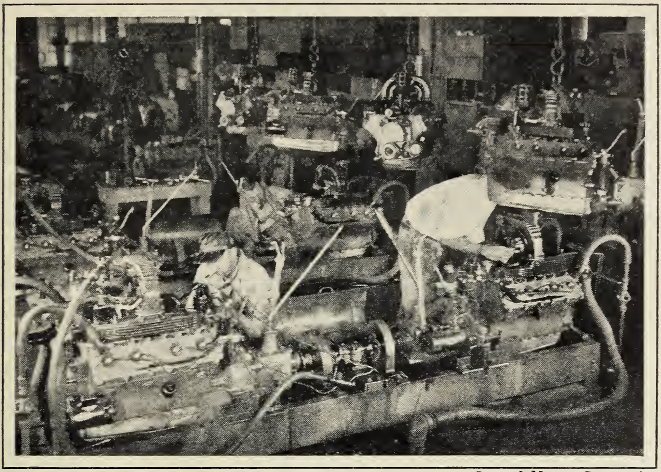
Now consider the second situation. Replace the modern engineers with a group of men from the far distant past. What can they do with this mass of raw material? Obviously, very little, if anything. They do not have the knowledge that we have today. The contrast will be even

Fig. 108. Large Quantities of Iron Ore (above), shipped from Mines Similar to the Lower Picture, help to furnish the Raw Materials of our Industrial Civilization

sharper if you imagine primitive man in a factory such as that shown in Fig. 109. These contrasting situations illustrate the growth in man's ability to use the materials of his environment.

The same situations might be considered in terms of many other modern things. A watch, a radio, a telephone, a locomotive, a bridge, and a skyscraper — each is composed of metals. As we observe the crude ore from which these objects are made and contrast it with the highly refined products of mechanical skill, we should have a feeling of deep respect for the inventiveness of the human mind.

Man did not all at once perfect his ways of doing things. Progress in ability to use material has been continuous



General Motors Corporation

Fig. 109. A Modern Automobile Plant represents the Results of a High Degree of Skill

through many centuries. During the time man has been on earth he has been a warrior, fighting for self-protection; a hunter and a worker, searching for food; and an artist, seeking ways to express his feelings. We today believe that he has reached a high development in these respects. While the whole story of this learning is not known, the growth in ability to use material must have come with the gradual assembling of ideas as they arose out of man's experiences. At first, crude materials were used to make crude articles. From experiences with crude articles clever men found ways to make finer ones. Finer articles in turn required finer materials. Thus progress in the use of material has come as men have seen the way to make better things and have then found better materials for making them.

Man's ability to use materials has increased gradually

We know of course that primitive man used as raw materials only wood, bone, and stone. It is only during the past few thousand years that he has acquired skill in metal work.

Anthropologists (men who specialize in the study of man and his culture) commonly recognize three ages of man: Stone, Bronze, and Iron. The Stone Age continued from the earliest period in the history of man until he learned to use bronze. The Bronze Age continued until he learned to use iron, and the Iron Age has continued until today. As you continue in your study, you may question what will follow the Age of Iron.

Scientists recognize three ages in the culture of man: Stone, Bronze, and Iron

These ages do not represent particular dates in history. You should think of them as representing merely the order of the development of culture in the various races. There are backward races today which we say are still living in the Stone Age. Why? Because they know little or nothing about the use of metals, and such tools as they have are made of stone. The American Indian, for example, with his weapons of stone and wood, was still living in the Stone Age when Columbus discovered America.

Perhaps you would like to know how scientists have reached their conclusions regarding this progress of man. The story is an interesting and a long one. Not all of it can be told here, but we can tell some of it.

The stage of culture reached by a people is revealed by the character of the artifacts (any objects made by men) which they produce. The period when artifacts were made chiefly of stone is the period we now call the Stone Age. Even this period shows progress within itself: some stone implements that scientists have found are rough things, made wholly by chipping; others are of polished stone. The evidence secured from the study of artifacts reveals that during most of the million years man has lived on earth he has lived in the Stone Age.

Stages of human culture are revealed by the objects made in that culture

The oldest artifacts made from metal are those of copper, silver, and gold. No one knows which of these metals was first used. There is evidence from the artifacts themselves

that all three were used long before the dawn of recorded history. Of them copper was the most abundant. Primitive methods of working metals were of course crude. Probably they were discovered by accident. As copper, silver, and gold are soft metals when pure and will not hold a cutting edge, they were probably used for making ornaments before they were used for other purposes. Artifacts of copper do show, however, that this metal was used to some extent for making weapons.

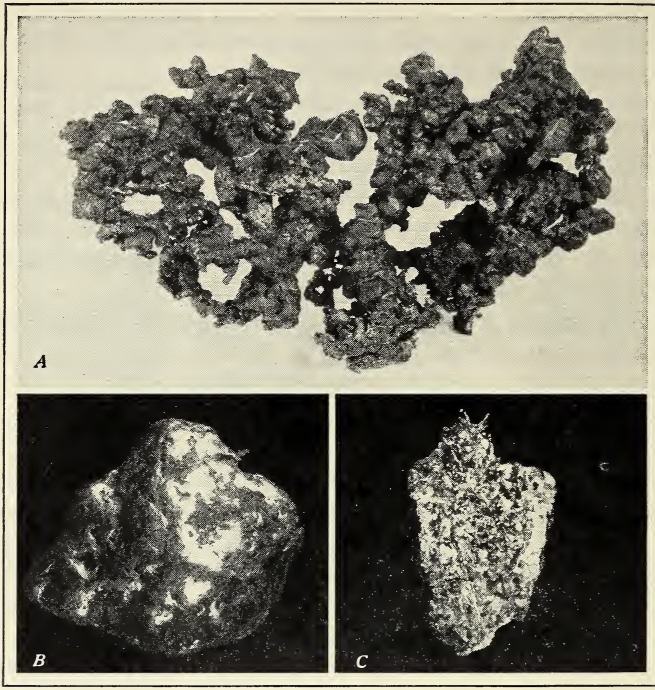
The oldest metal artifacts are made from copper, silver, and gold

Why should primitive people have depended upon these metals? The answer probably is that while they are not found in great quantities, they are found free; that is, they are not combined with other elements. To use them, then, man did not have to know anything about the processes by which metals are extracted from ores. It seems reasonable to believe that our primitive forefathers, discovering nuggets of these metals similar to those shown in Fig. 110, tried to fashion them into tools and trinkets, and found that for some purposes they were superior to stone.

Primitive man worked with metals found free

Sometime after man learned how to work metals, he acquired skill in extracting them from ore. Here again it is quite possible that the discovery was accidental. But however it came about, some intelligent members of the race realized the importance of the find and added it to their increasing store of knowledge. Then someone found how to combine various metals. This too was extremely important; for when certain metals are mixed with other metals, they form what are known as alloys. Some alloys, or mixtures of metals, are harder than any of the metals which go into their composition. These alloys are therefore much more durable than the pure metal itself. Take a common example. Copper mixed with tin forms bronze. A one-cent piece is made

Extracting metals from ores and combining them with other metals marked a great forward step in human progress



A. M. N. H.

FIG. 110. A Few Metals are found as Nuggets in a Free State

A, a nugget of copper; *B*, one of gold; *C*, one of silver

of bronze. If you compare this coin with a sheet of pure copper or tin, you will see that the bronze is much harder than either. Primitive people stumbled somehow upon this discovery. As they learned to make bronze and to use it in making weapons, tools, and works of art, the Stone Age changed to the Age of Bronze.

And then came another discovery. Sometime after primitive men had learned to make and to use bronze, they discovered how to separate iron from its ore. This marked another cultural step forward, and the Age of Iron followed the Age of Bronze.

We live today in the Age of Iron, for iron more than any other metal determines the character of our culture. Through the use of iron we have learned to develop power from natural resources and to use it to drive machinery. The influence of this development on culture of today is so far-reaching that the present is frequently referred to as the Age of Power. Anthropologists commonly consider that the Age of Power lies within the Age of Iron, for the use of metal is obviously essential to the development of power.

The modern age is called the Age of Iron

In this brief introduction we have tried to picture in general terms the sweep of man's progress in the use of materials. Now let us examine the ages of man with a little more care.

B. How did the Use of Stone help Men to control their Environment?

It was fifty thousand to a hundred thousand years ago that Neanderthal man lived in Europe. Since much of the Northern Hemisphere at this time was covered with ice, the climate even in southern Europe must have been cold. Primitive men, with their families, took to caves (such as shown in Fig. 111) for protection. Scientists have unearthed materials left by these ancient people in cave dwellings. Neanderthal man must have fed upon animals, for the bones of animals are found beside the remains of fires. He used stone implements, and they too have been found there.

The Neanderthals lived in the Stone Age

Imagine yourself back in this setting. Some of the older men are working in stone. Some of the children are imitating their elders, thus acquiring their skills in one of the oldest forms of education. Finished pieces of stone are at hand for use as needed. There are tools for skinning animals, the skins being used for protection against the cold. There are tools for cracking bones; these primitive people

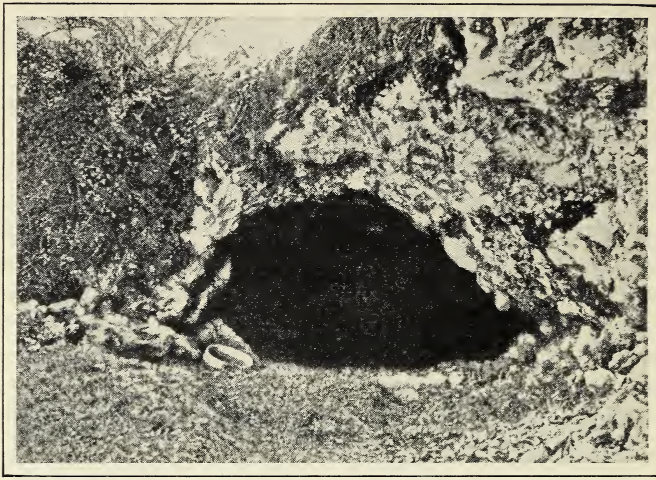


Fig. 111. Some Primitive Men lived in Caves

These furnished a measure of protection from rain and cold, and were resorted to during ages when the climate was colder

are evidently fond of bone marrow. There are weapons for hunting and for self-protection. None of these tools and weapons is made of anything but stone. Photographs of artifacts left by Neanderthal man are shown in Fig. 112. Here is a hard life, to be sure, but in their different implements these primitive people are already exercising a measure of control over their environment. In some such setting as this human culture had its origin.

During the Stone Age man showed an improvement in his ways of working in stone

You may know something of another early race called the Cro-Magnons. These were a race of people who took the place of the Neanderthals in southern Europe sometime after the ice of the last great ice age had begun to recede. These men were of a higher stage of culture than any who had lived before them. They used stone for tools and weapons, just as the Neanderthals had; but the im-

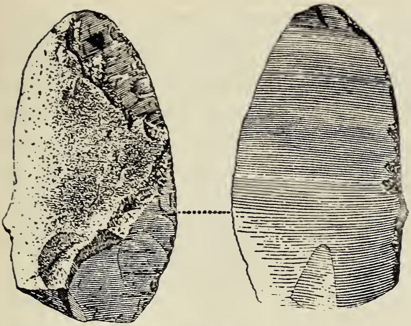


Fig. 112. Neanderthal Man exercised a Measure of Control over his Environment[1]

What uses do you think were made of these crude stone implements?

plements which they made showed finer finish. Stone implements were made in greater variety, and there were evidences of attempt at artistic effect. These men also used bones and horns as materials for their tools, some of which were beautifully decorated. Drawings of some of their tools are shown in Fig. 113. Cro-Magnon men were considerably advanced over the Neanderthals in their ability to battle with and to control the forces of their environment. But, like the men who preceded them, they too were replaced by more advanced races.

If we step forward now to a period about ten thousand years ago, we find Europe peopled with races living in small scattered communities, beginning to cultivate the land. Although

Fig. 113. The Stone Implements of Cro-Magnon Man show an Improvement over those of Neanderthal Man[2]

What improvements do you see?

[1] From G. G. MacCurdy's *Human Origins*, Vol. I. By permission, D. Appleton and Company, publishers.

[2] From G. G. MacCurdy's *The Coming of Man*. By permission, The University Society, publishers.

they still worked in stone, they were so much more skillful than earlier men that they were called men of the New Stone, or Neolithic, Age. The Neanderthals and Cro-Magnons belong to what we call the Old Stone, or Paleolithic, Age. Implements and art work of Neolithic men are shown in Fig. 114. Compare these pieces with the work shown in Figs. 112 and 113.

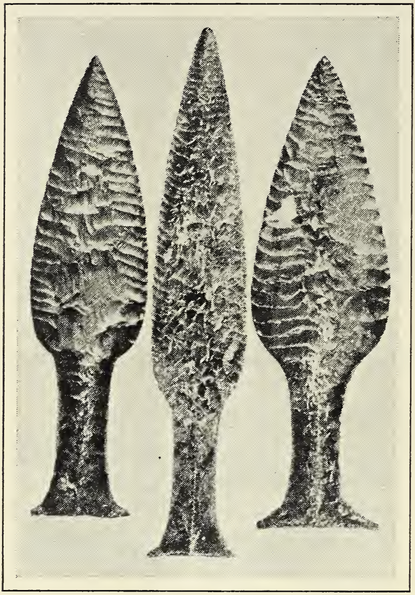


Fig. 114. The Work in Stone of Men in the Neolithic, or New Stone, Age was Far Superior to that of Races Previous to that Time[1]

Compare these implements with those in Figs. 112 and 113

Probably the greatest advance of Neolithic over Paleolithic peoples is their ability to fasten wooden handles to their stone tools and weapons. This may seem a small thing, but it marks great progress. Evidence of that progress is found in the fact that the Neolithic men crowded out the Cro-Magnons, just as Cro-Magnons had at a much earlier time crowded out Neanderthals.

After the beginning of the Neolithic Age progress in cultural development seems to have been rapid. There were more kinds of implements with which to work. With greater variety of implements there was opportunity for

[1] From G. G. MacCurdy's *Human Origins*, Vol. II. By permission, D. Appleton and Company, publishers.

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Fig. 115. Many Ancient Ruins testify to the Ability of the Egyptians, Phœnicians, and Babylonians to produce Beautiful Objects from Stone

This ancient temple at Luxor, on the site of ancient Thebes, Egypt, was built about 1400 B.C.

richer experiences and so for speedier progress in learning. Within a few thousand years after man became able to polish stone and to fasten handles on axes he learned to write. From that time onward we have his written record as well as the record left by artifacts. Modern races seem to have descended from these Neolithic people.

Man's work in stone did not end with the Neolithic Age. The ruins of monuments of stone (Fig. 115) and the bits of beautiful statuary discovered among them in Egypt, Phœnicia, Babylonia, and other countries furnish a record in stone of the cultural developments of old civilizations. The Greeks, who realized the possibilities of work in stone, made their first appearance on the historical scene about 1500 B.C. One thousand years later the civilization of the Greeks had reached its greatest height. They had built

FIG. 116. The Greeks are Famous for their Beautiful Work in Stone. This Structure is made of Marble

The temple shown was built in the fifth century B.C., on the Acropolis in Athens

the great cities of Athens and Corinth, and within them they had constructed beautiful buildings and monuments. Some remains are still to be found, as shown in Fig. 116. The work of the Greeks in marble statuary has never been equaled. It is indeed a long step in the progress of man from the crude pieces of stone shown in Figs. 112, 113, and 114 to the fine marble statuary shown in Fig. 116. The period of time required for this progress was from fifty thousand to seventy-five thousand years.

People living in relatively recent periods of history have left evidence of work in stone

C. In What Ways did Men of the Bronze Age control their Environment?

It is reasonable to think that primitive man might try to make use of any materials he happened to pick up. Perhaps because of its unusual appearance he picked up a copper ore. One ore, called cuprite (Cu_2O), is a reddish powder. When this ore is heated in a strong wood fire, some copper is formed. Although the chemistry of the process was certainly unknown to early man, it seems reasonable that a primitive experimenter should have discovered in some chance observation how to separate copper from its ores. There is convincing evidence that these methods were known well before the dawn of recorded history.

The discovery of bronze was probably accidental

The process of making bronze seems simple after it is once learned. Bronze is an alloy of copper and tin and may be made by melting and mixing these two metals. It may also be made directly from the ores of copper and tin. It seems likely that the first bronze was made from the ores rather than from the pure metals. The mineral from which tin is obtained is called tinstone. It is a compound of tin and oxygen having the formula SnO_2. (Sn is the abbreviation for the Latin word *stannum*, which means "tin.")

Bronze was found to be much more suitable for certain uses than stone. For one thing, it will take and hold a cutting edge. With it man could make better weapons for defense and for killing game. He could make better tools, and thus the possibilities for artistic expression were enlarged. Here, then, was a substance that could furnish many new experiences. New experiences are the basis of learning. From all evidence advances in learning during the few thousand years of the Bronze Age were very much greater than the advances through the hundreds of thou-

Bronze offered greater opportunity than stone for improved tools and other artifacts

sands of years of the Stone Age. Perhaps you have read accounts which tell this story at length. If not, you will wish to get some at your library.

Bronze has been used in the construction of carts, chariots (Fig. 117), and armor, and in sculpture. The Greeks and Romans, who showed such great ability in their work in stone, also excelled in bronze. Some famous statues in bronze are shown in Fig. 118. Some of the greatest masterpieces the world has seen were made during the period of five hundred years which came just before the Christian Era.

D. How does the Use of Iron help Men to control their Environment?

The story of man's progress in the use of iron is similar to the story of his progress in the use of bronze. The effect of iron on the changes in culture has been greater than the effect of bronze, partly because iron lends itself to more uses and partly because ores of iron are much more abundant than ores of copper.

Iron is more useful than bronze

Hematite is the most common form of iron ore. This is a form of iron oxide, a combination of iron and oxygen, with the formula Fe_2O_3. (Fe is from the Latin word *ferrum*, which means "iron.") As you have seen, it was not many thousand years after men learned to work bronze that they learned to work iron. Thenceforth iron as well as bronze was used for tools and weapons.

Iron is separated from the ore by heating a mixture of ore and charcoal in a furnace. A high temperature is required for the chemical change. The great difficulty for the primitive ironworker was to get the furnace hot enough. Bellows made of the skins of animals were used to supply a forced draft. Fig. 119 shows how one of the primitive furnaces was used. As the workman raises his foot, he enlarges the space within the skin, and air enters to fill it.

Metropolitan Museum of Art

FIG. 117. The Artistic Ability of Some Early People, as expressed in Bronze, was Quite High

This ancient chariot, made of bronze by the Etruscans, was found in 1902 in a tomb near Monteleone, Italy

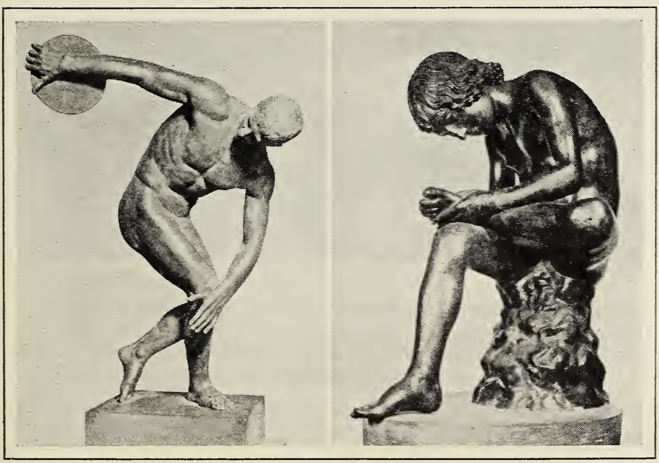

FIG. 118. Bronze was used for Statuary Too

These statues, "Discus Thrower" and "Boy with a Thorn in his Foot," date back to about the middle of the fifth century B.C.

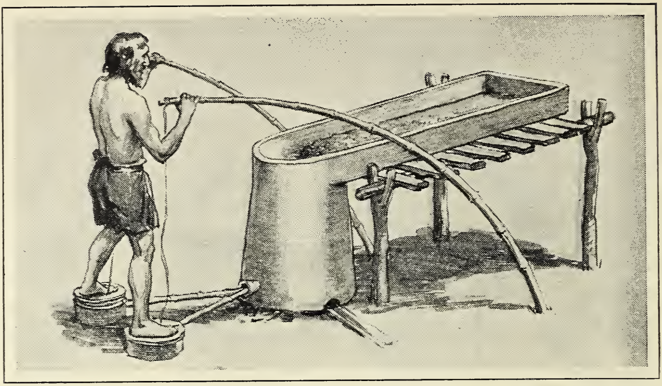

Fig. 119. The Primitive Blast Furnace was a Simple and Crude Affair

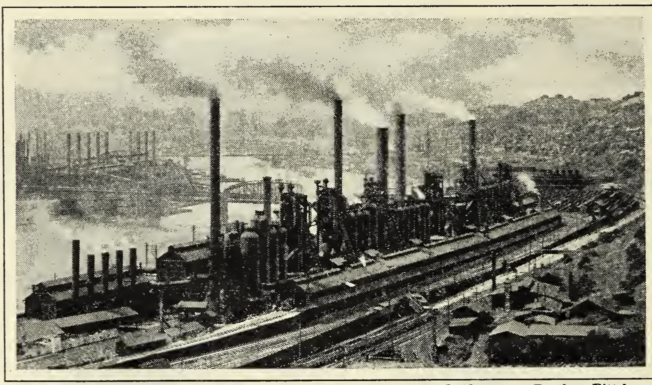

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Fig. 120. One Measure of the Progress of Man in the Iron Age is found in a Comparison between the Primitive Blast Furnace in Fig. 119 and the Great Number of Modern Furnaces, such as the Above, which we have Today

As he throws his weight on the skin, the air is forced out through the furnace. This seems crude, yet it represents a clever invention. From this simple beginning has come the modern blast furnaces illustrated in Fig. 120.

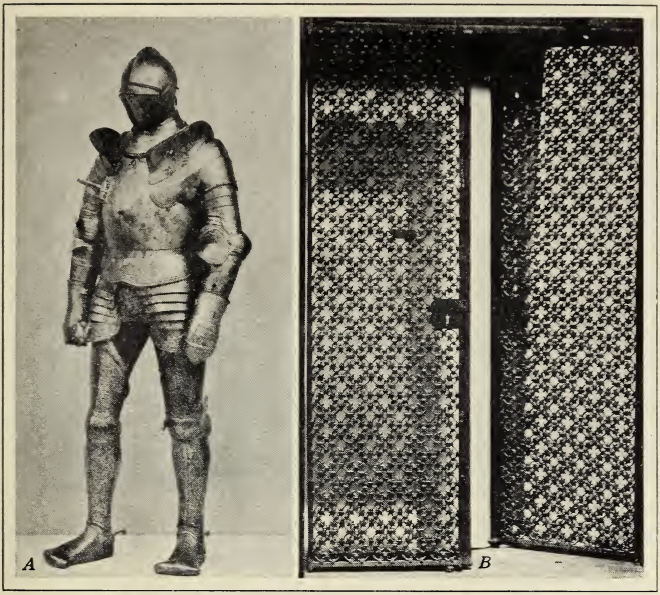

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FIG. 121. Some of Man's Early Work in Iron was Not Only Beautiful but Indicative of a High Measure of Ability to use Materials

Both the suit of armor (*A*) and the doors (*B*) were handmade

Uses for iron multiplied rapidly. Like stone and bronze, iron was used in making weapons for defense and for hunting, in making tools, and in art. Iron was used for armor and for doors, gates, and fences. In the construction of these there was evidence of a great deal of artistic ability, as shown in Fig. 121.

As men continued to enlarge their experiences through work with iron, they learned more and more uses for it. Illustrations of some of its many uses are seen in the remains from ancient civilizations. A most important use for iron in the form of steel was for making sharp-edged tools. Even today no other metal is as useful as steel for this purpose. The methods of making steel are given in a later chapter.

FIG. 122. Robert Fulton was one of the First Men to apply the Principle of the Steam Engine in a Steamboat

The first trip of the *Clermont* was made in 1807

E. What is the Age of Power?

The Age of Power came as man learned to use energy from waterfalls

The greatest achievement of the Iron Age came when James Watt improved the Newcomen steam engine and thus extended its use. He invented a piston and a cylinder similar to the ones used today. Watt took out his first patent in 1769, and the first successful engine was in operation in 1776. Within twenty-five years this engine was used widely to develop power for paper mills, textile mills, and other types of factories. In 1807 Robert Fulton used a steam engine to drive a boat up the Hudson River. An artist's idea of this event is shown in Fig. 122. In 1829 George Stephenson used a steam engine to drive a railway locomotive. Before 1900 the gasoline engine was successfully used to drive motor cars, and soon after 1900 it was

Fig. 123. George Stephenson, *who made the First Successful Locomotive* (*1781–1848*)

When George Stephenson was seventeen, he could not read a single book, for George had long since been at work with his father in a coal yard. (In those days there were no child-labor laws!) The father was an engine fireman, and George learned about engines from him. James Watt, the genius who had made steam engines practical, was their hero. And it was the desire to find out more about Watt that now sent young George to night school · Soon he himself became engineman in a coal yard at Killingworth, with an idea in his head to make a "travelling engine" that would go all about the yards. This idea, as you know, resulted in his famous *Rocket* and the first steam railway · Stephenson also invented a safety lamp for use in the mines. It was much like the lamp that Sir Humphry Davy was experimenting with at the same time. There is little doubt that the two inventors worked separately and hit upon the same invention because it was so badly needed. But Davy got the credit. It was another example of two men's having the same idea in the same period, when the time was ripe for it. Adams and Leverrier discovering the planet Neptune, Newton and Leibnitz inventing the calculus, Darwin and Wallace with their theory of evolution, or Langley and the Wright brothers in aviation are other examples · George Stephenson made the first locomotive that ran on rails. His son Robert carried on. With inherited ability coupled with a good education—which his father had lacked—Robert Stephenson made a name not only in engine-making but in bridge-building in both England and Canada.

successfully used to drive airplanes. Thus there developed all kinds of machines, and with them came a rapidly increasing demand for iron. Now machines are being used to do the work of the world.

The Power Age created demands for other metals

With the development of machinery there has been an increasing demand for other metals besides iron. Metals of high strength are required for axles of automobiles. Metals that are strong and low in density are required for airplanes. These special metals are alloys, usually of iron with some other metal. Vanadium steel has great strength. Nickel steel is extremely hard. Tungsten steel is used for drills. Skilled workmen are continually seeking to make steel which shall be better suited for particular uses.

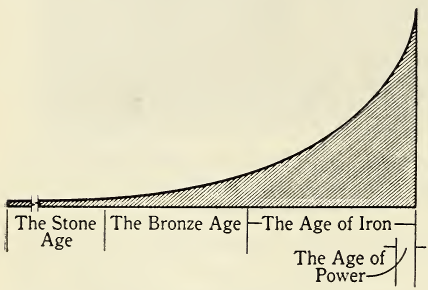


Fig. 124. One Measure of Changes in Culture through the Various Periods of Development is the Rate of Increase in using Materials

What does the future hold in store?

The electrical industries make heavy demands for copper. Lead is used for storage batteries. Tin and chromium are used for plating. Zinc and lead are used for paint. You will learn more about all these metals at a later time.

Each advance in the long history of man's activities has been marked by an increase in the use of material. In fact, one measure of cultural change through the various periods of development is the rate of increase in using material. This is all shown in Fig. 124. Of course the rate of increase cannot be determined with exactness, but from general considerations we know that the increase through the ages must have been about as shown in the graph.

As we have said, when the range of experiences open to man enlarges, his rate of learning increases. The Stone Age was one of slow progress. Minerals, including ores of common metals, coal, and petroleum, lay in the ground, but no man knew of their existence nor how to use them. The rate of change quickened when man learned to use metals. It quickened still more when he learned to use energy from fuels and falling water. We have advanced a century into the Age of Power, and still the rate of using material goes on, ever increasing. As man expands the range of his experience, will he continue to increase his demands for materials? If so, where will it end? Can progress (as shown in Fig. 124) continue upward and upward or must it turn downward? What does the future hold in store?

The future may bring man out of the Iron and Power Age into new cultural eras

It is possible that the far distant future may bring a new culture. The stocks of iron ore are being reduced, and more and more effort is required in mining. As the effort increases, men will look about for substitutes for iron. It may be that the kind of material that will mark the next age of man is unknown to us today, just as bronze was unknown to men of the Stone Age and iron was unknown to men of the Age of Bronze.

One evidence of man's cultural changes is his increasing ability to use the materials of his environment.

Can You Answer these Questions?

1. What are the evidences of events that came before the time when there were written records?

2. What is meant by an age? What bases are there for dividing man's life on earth into the three ages of stone, bronze, and iron?

3. What is the evidence that the Age of Iron represents an advance in culture over the Age of Bronze?

4. Why did primitive people depend largely upon copper, silver, and gold for their metals rather than upon those which are today cheaper and more plentiful?

5. The statement is made that the use of metal is essential to the development of power. Why should this be?

6. Support with evidence the statement that Neanderthal man ate the marrow of bones.

7. What important effect did the inventions of Stephenson, Watt, and others at the beginning of the Age of Power have upon man's progress?

Questions for Discussion

1. What are the evidences that we live today in a culture that is more advanced than the culture of the ancient Greeks?

2. Do you think that the curve of progress shown in Fig. 124 will continue to rise? How should you support your beliefs?

3. Can one say fairly that primitive man was less intelligent than we are today?

4. Could we live in an age of metals if we did not also live in an age of power?

5. Do you think that any of man's cultural progress has been due to chance discoveries? Should you say that more of it has been due to chance than to careful studies and experiments?

6. Why do you think that people today imitate Greek temples in architecture?

7. How do the methods used to find new alloys for airplane engines compare with the methods by which the way to make bronze was discovered?

Here are Some Things You May Want to Do

1. Trace the history of the development of the automobile or some other machine, either by dates or by a succession of pictures.

2. Compare flint, granite, quartz, and marble. Which one of them was used by the Indians to make stone implements? Why did they use this one? Which ones were used by ancient peoples in making statuary? Why?

3. Trace the history of the art of writing. Work this up as a special topic, studying the forms of letters, materials for writing, and the kinds of records kept.

4. Trace the development of the use of coal and petroleum and write an additional chapter for this book, entitled "How has Man's Progress depended upon his Use of Carbon and its Compounds?"

5. The graph of progress shown in Fig. 124 is necessarily small. You might wish to extend this graph by filling in some of the items for the various eras. Your work in history should help you here. If carefully made, such an enlarged graph might form a valuable addition to your science room.

Chapter XI · What is the Origin of Iron, and How is it made into Steel?

In your reading of newspapers and magazines you have doubtless found a great many references to this Iron Age and Power Age in which we live. Perhaps you have been puzzled by these terms. Has not every age been an Iron Age and a Power Age? Your present study is making you realize that we today live at a time when iron and power determine the character of civilization itself.

Iron and power determine the character of modern civilization

Think of the many things that are composed wholly or in large part of iron. Rails and railroad equipment, automobiles and trucks, tractors, skyscrapers, bridges, ships, heavy machinery for manufacturing industries, and thousands of small articles like saws and hammers and wrenches are made from iron and steel. Try to name an article you use that has not been made or in some way worked upon by tools or machines of steel. Take, for example, the bread you eat. Machines, as you can see from Fig. 125, are connected with every step of the process that changes it from grain to the product that reaches your table: the plow that turned the soil; the tractor that pulled the plow; the combine that harvested and threshed the grain; the tractor that pulled the combine; the truck and the train that hauled the grain to the mill; the carriers that delivered the flour to the bakery; the steel machinery that mixed the dough, baked the bread, and delivered it from the ovens ready for use.

Countless other examples might be given. Your clothing, your house, your furniture, your parks, and your roadways are produced or maintained by steel machinery. The steel itself is made by machines. It seems almost as if our whole lives at present depended upon iron and power.

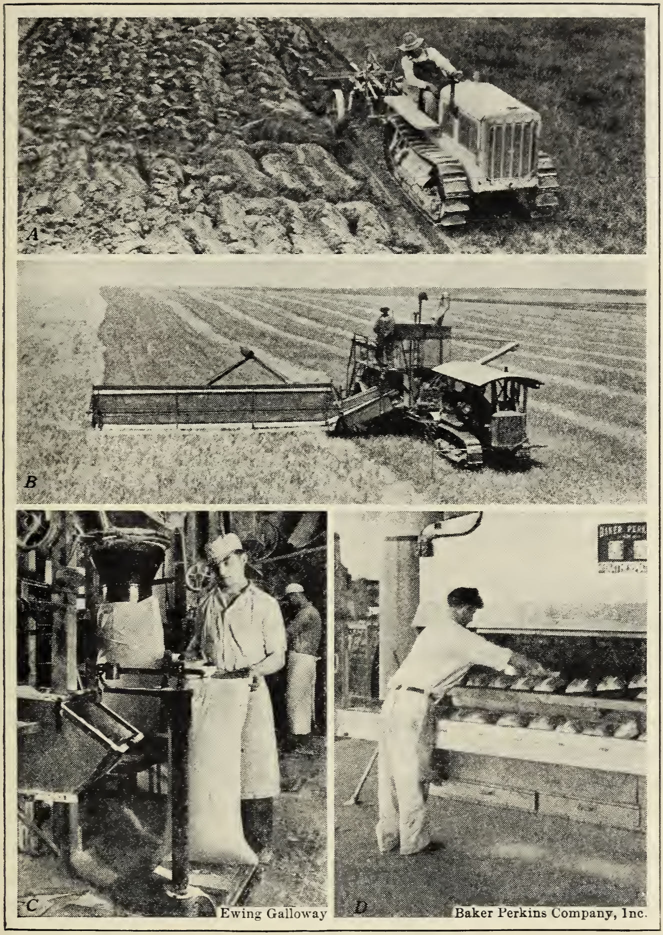


Fig. 125. Many of the Processes by which we obtain our Food are Possible only because of the Use of Iron, Steel, and Other Metals in Machinery

Here are four steps in bread-making: *A*, plowing with a tractor; *B*, harvesting with a combine; *C*, milling the wheat; *D*, bread coming from the oven. This is an age of iron and of power

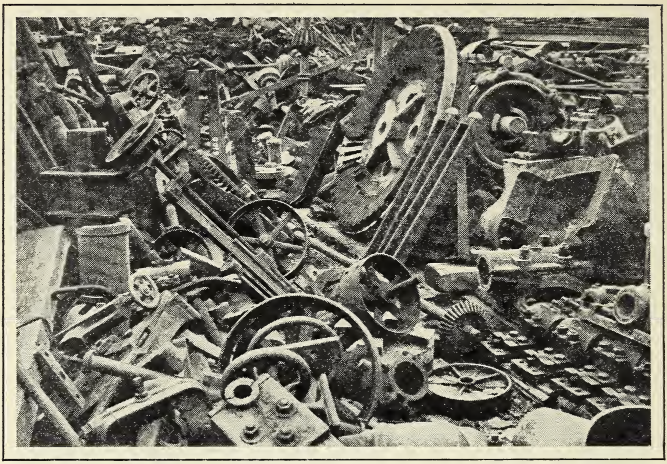


Fig. 126. Iron and Steel exposed to the Action of Air rust away and become a Part of the Soil

Scenes such as the above may represent real economic waste

As one considers the tremendous output of machinery over the last few decades, one wonders where in the world it has all gone. Styles change rapidly in automobiles. More and more powerful locomotives pull our trains. Faster and faster airplanes cross the continent. More and more complex machinery is used in industry. But what has happened to the old car, the slower airplane, and the simple machine? Perhaps you are familiar with a scene such as that in Fig. 126. From similar yards a great deal of the worn-out machinery is returned to the iron and steel mills as "old iron." Here it is melted and used again in the manufacture of new machinery. But a very large amount is wasted. In dump heaps about our cities there are discarded automobiles, steam boilers, and engines. As time passes, this iron and steel rust away and become a part of the soil. This iron is lost. Obviously we are using our natural deposits of iron

Iron is wasted in great quantities

at a tremendous rate, for the thousands of tons of iron and steel that rust away every year must be replaced. Where does this iron come from? What is the origin of iron ore? How do natural forces cause it to form? How is iron separated from the ore? How is it made into steel? Is there an endless supply of ore?

It is important that we think through these questions and others related to them.

A. What is an Ore, and How have Ores been Formed?

Suppose you had the skill to pick out from a sample of soil the chemical elements of which it is composed. What would you find? Certainly there would be oxygen, silicon, aluminum, and iron; most of the sample would consist of compounds of these four elements. But using the more careful, searching methods of a chemist, you might find traces of lead, zinc, copper, tin, and possibly silver and gold.

Similarly, if you were to take a glass of water from the ocean, evaporate it, and analyze the salt that was left, you would find, along with other substances, traces of compounds of iron, aluminum, lead, zinc, tin, and copper, even including silver, gold, and platinum.

Iron is one of ninety-two elements which compose the crust of the earth

From such examinations you would probably decide that the substances which make up the surface of the earth are composed of many elements. This conclusion would be correct. The earth is composed of ninety-two chemical elements. Iron is one of these elements, although not the most abundant. You know something of the relative abundance of these elements. Oxygen in the air and in combination with other elements in rock and soil makes up nearly 50 per cent of the earth's crust; silicon makes up another 25 per cent. Silicon dioxide (SiO_2), commonly called silica, is a compound of these two ele-

ments. Sand and sandstone are mostly silica. Aluminum ranks third in abundance. It makes up 8 per cent of the earth's crust. Iron ranks fourth, making up 5 per cent of the total. Adding these figures, you find that four elements make up over 87 per cent. These together with ten others make up 99 per cent. But what of all the other elements? One thing is certain: they must be very scarce, since fourteen of the ninety-two elements make up more than 99 per cent of the total. It may seem strange that none of the familiar metals except aluminum and iron are included within the fourteen most abundant elements. In fact, all of the world's copper, lead, zinc, tin, and nickel taken together make up far less than one tenth of 1 per cent.

The cost of metals depends partly upon the ease with which they may be extracted from ore

You may wonder why certain metals cost so much when compounds containing them may be picked up anywhere. The answer is not hard to find. While many metals are present in soil and sea water, the concentration, or percentage to be found in a given quantity of soil or water, is so low that they cannot profitably be extracted. As a striking example, consider gold. It has been estimated that in all the water of the oceans there is 800,000 times more gold than there is in all the banks of the world. Before this gold would be valuable, however, it must be taken from the water. This would be a difficult task, and the expense involved would be greater than the value of the metal which could be obtained.

There are certain areas distributed over the earth, however, from which metals may be extracted with profit. These areas contain deposits of ores. There are deposits of iron ore, for instance, containing more than 50 per cent iron. Here the concentration is high enough to make the labor involved in extracting the metal well worth the pains. What is the origin of these deposits? Natural forces operating through many millions of years have caused the deposits to form. Let us look at these forces.

You may get some understanding of the manner in which ores have been formed if you follow the changes that must have occurred when a great mass of molten rock moved upward from the interior of the earth, hardened on or near the surface, and was later worn away by weathering and erosion. You already know something about these forces.

Molten rock is not a simple substance but is a mixture of chemical compounds together with a small amount of some free elements. These compounds and free elements are called minerals. A mineral is a naturally occurring substance with a definite chemical composition. Silica (SiO_2) and magnetite (Fe_3O_4), for example, are minerals. Such minerals as the oxides of iron are sources of our important metals. What is an ore? When these minerals are sufficiently concentrated in one deposit, they form a commercially valuable ore.

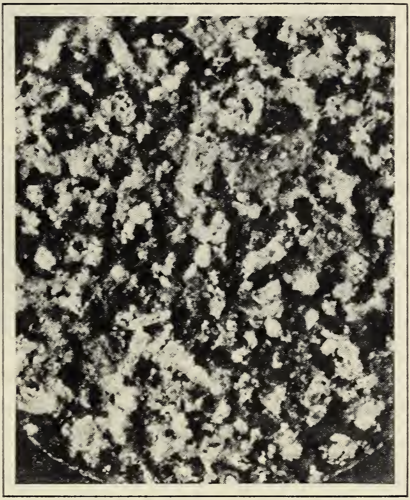


Fig. 127. Granite is an Igneous Rock, made up of Many Different Minerals

The granite surface shown here has been magnified many times

The most familiar igneous rock (that is, a rock which has been made by the cooling and solidifying of hot molten matter from deep within the earth) is granite. You may see with a small magnifying glass the tiny crystals of some of the minerals of which it is composed (Fig. 127). The shiny crystals are quartz, a form of silica; the smooth flesh-colored ones are feldspar; and the dark crystals resem-

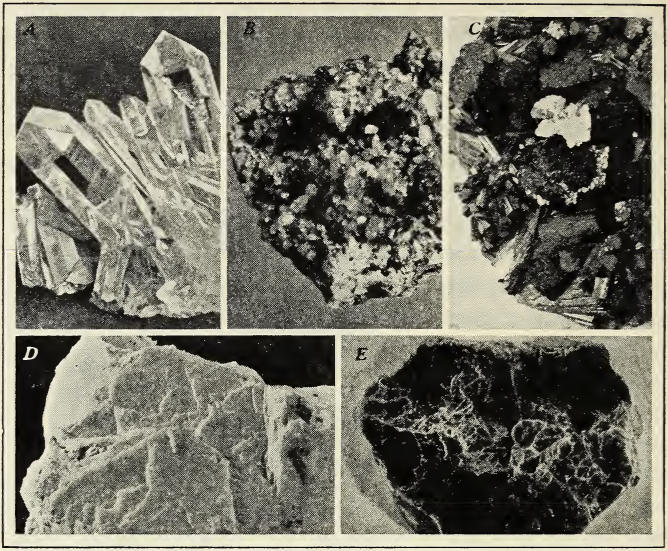


Fig. 128. Different Minerals have Different Characteristics

A, quartz; *B*, hematite; *C*, magnetite; *D*, feldspar; *E*, Mica. Can you find any differences in these minerals?[1]

bling thin sheets are mica. Perhaps you have seen these and other minerals on display in a museum. Fig. 128 will give you an idea of the appearance of some common minerals.

The formation of minerals depends partly upon their melting points and their density

Let us imagine that you could watch the changes which must have taken place in the formation of igneous rock. A molten mass of rock moves upward toward the surface of the earth and slowly cools. You will see, while the rock is liquid, that the more dense minerals tend to separate from the less dense ones. The reason for this is that in a liquid the densest materials sink deepest and the least dense rise to the surface. In a molten mixture of silica and magnetite, for instance, you would expect to

[1] Photographs *B*, *C*, and *D*, used by courtesy of American Museum of Natural History.

find the less dense silica above the more dense magnetite. Copper, silver, and gold, being more dense, would sink beneath the magnetite.

As the rock cools, it slowly hardens. Those minerals contained in it which have the highest melting point will harden into crystals first. Do you see why? The hardened mica, feldspar, and quartz will then tend to separate from the liquid copper, silver, and gold.

You can see, therefore, that minerals are not evenly distributed through igneous rock. One sample of rock may contain more of the minerals with high melting points, another more of the minerals with low melting points. One may contain more of the denser minerals, another more of the less dense minerals. Thus one rock may contain enough magnetite to make it valuable as iron ore, and another may contain enough gold to make it valuable as gold ore.

Mineral deposits are formed by natural forces working on the surface of the earth

Now follow the changes that occur as a mass of igneous rock is worn away by weathering and erosion. As the rocks are decomposed, or broken up, most of the minerals contained within them are changed to some extent by chemical action with oxygen, carbon dioxide, and water. Running water carries the pieces away. The finest and least dense bits, such as those formed by weathering of mica and feldspar, will of course be carried farthest in a given period of time. They will appear as mud, or silt. Pieces larger and denser than silt, such as the quartz crystals released from granite, will be carried less readily than the smaller bits. They will appear as sand. Running water tends, therefore, to separate silt from quartz, quartz from magnetite, and so on through the list. In this manner all the materials of which the rock is composed are sorted. The densest minerals are moved the least distance and the least dense minerals are moved farthest. By the action of running water minerals alike in density are deposited together and minerals unlike in density are separated.

Let us summarize these processes, since a clear understanding of them is important to our story of the use of ores. Molten matter containing a mixture of minerals flows upward from within the earth and hardens on or near the surface, forming igneous rock. As the molten mass cools, minerals with higher melting points tend to separate from minerals with lower melting points. Minerals of less density separate from minerals of greater density. As time passes, these igneous rocks are decomposed. As the rocks are decomposed, running water separates the less dense minerals from the denser ones. As a result of these and other processes minerals from the rock are sorted and deposited as ores. Thus the metals of which an automobile axle, a piece of wire, a coin, or even a modern ocean liner, such as the one in Fig. 129, is composed had their origins in hot rock that once came up from within the earth.

Except for the succession of changes that has just been described, continuous through many millions of years, this Age of Iron and this Age of Power could not have been.

B. What is Iron Ore, and How Abundant is It?

The richest deposit of iron ore in the United States and one of the richest in the world is in Minnesota and Michigan. It is rich because it contains a large percentage of hematite, a form of iron oxide with formula Fe_2O_3. That is to say, this iron ore is about 70 per cent hematite. The remainder is a mixture of other minerals, chiefly silica (SiO_2). One hundred pounds of the ore will produce somewhat more than 50 pounds of iron.

The igneous rock from which this deposit was formed must have contained a considerable percentage of an iron-bearing mineral. By weathering and erosion the rock was decomposed. The iron-bearing minerals were changed to iron oxide (hematite), which is not soluble in water. Other minerals which were soluble were slowly washed away.

Keystone

Fig. 129. The New *Queen Mary* is an Illustration of Man's Ability to use Metals

Some of the less dense minerals were also washed away. In this way the deposit of hematite was concentrated.

These physical conditions during which weathering and erosion concentrated this rich deposit of ore must have continued for an extremely long time, and yet we know that the deposit of ore was already formed before the beginning of the Paleozoic era, the middle one of the five great eras into which earth history is commonly divided. As time went on, these deposits were overspread with earth.

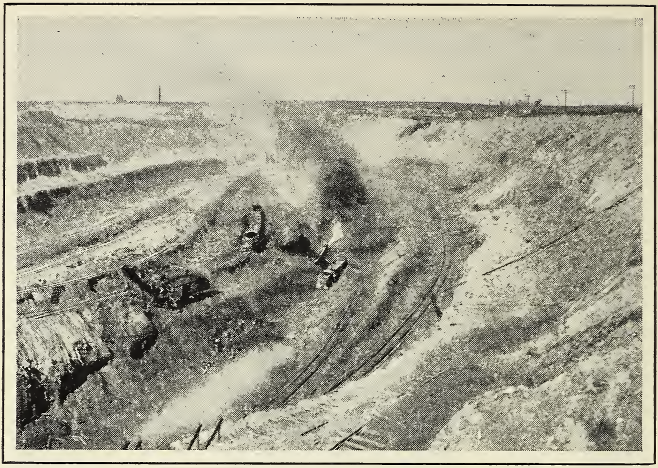


Fig. 130. Open-Pit Mining is often used in Removing Iron Ore from the Ground

What advantages over the closed-mine type are there in this type of mining?

The layer of earth now covering this ore is not very thick. It must be removed, of course, before the ore can be obtained. In mining, the ore is broken by blasting and taken by steam shovels from an open pit, such as the one shown in Fig. 130. It is then shipped to industrial centers to be made into pig iron.

Iron ore is found in many parts of the world

There are numerous deposits of iron ore. This ore is in fact more abundant than ores of any other metal. About 85 per cent of the iron used in the United States comes from the Lake Superior region. In Alabama there is a large deposit of hematite, but it is less easily mined than the Lake Superior ore. In New York, New Jersey, and Pennsylvania are deposits of magnetite (Fe_3O_4), of which we shall hear presently. These were worked for ore before the Lake Superior mines were opened; but the cost of mining in these newer mines is so much less than the cost of mining in the

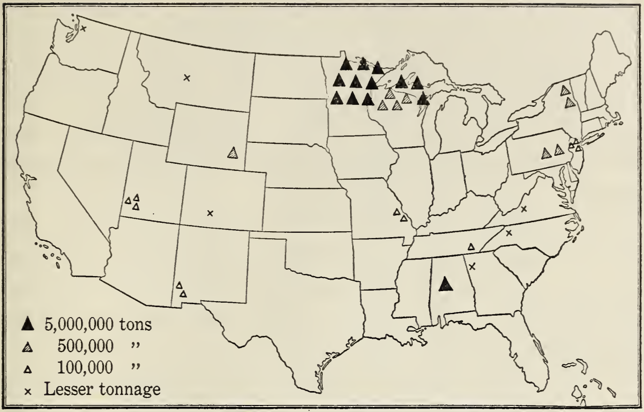


Fig. 131. Iron Ore is abundantly distributed in Various Parts of the United States

Where are the largest deposits found?

older mines that most of the magnetite mines in New York and New Jersey have been forced to close. The iron minerals are still there, however, and the mines could be reopened if the need should arise.

Fig. 131 shows the location of deposits of iron ore in the United States. Other famous deposits of iron ore are in northern France and southern Germany, in Brazil, South Africa, Newfoundland, and Cuba. There is no immediate danger of shortage of this important metal.

C. How is Iron Separated from Iron Ore?

The two ores of iron used more commonly are those containing hematite (Fe_2O_3) and those containing magnetite (Fe_3O_4). Perhaps you would like to see samples of these ores. You can probably obtain them from a chemical supply company. You must understand that the ore is not a pure mineral, but a mixture of hematite or magnetite with other minerals. In asking for samples ask for the ores and not the minerals.

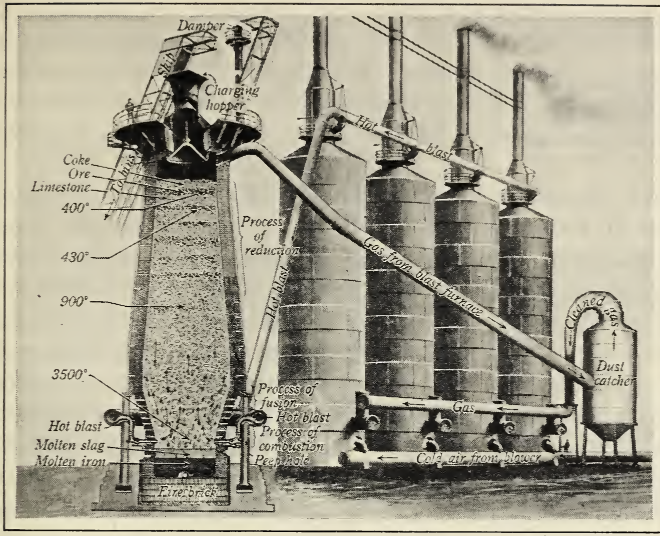
Hematite ore is reddish brown in color. Certainly there is little in its appearance to suggest that it is the material from which objects like steel rails and watch springs may be manufactured. Magnetite is darker, and the crystal structure of the mineral is more in evidence. Some magnetite ores have magnetic properties; that is, they act like magnets.

Iron is separated from ore by a chemical process. Suppose we follow step by step what happens when pig iron is made from hematite ore. In this process you must recognize two important things. First, hematite ore is a mixture of the mineral hematite with other earthy materials; the earthy matter must be separated and removed. Second, hematite (Fe_2O_3) is an oxide of iron (that is, a compound of iron and oxygen); before the iron is of any use it must be separated from the oxygen. A little later we shall describe the chemical changes.

Iron is separated from iron ore through a chemical process

The process of separating iron from iron ore is carried out on a huge scale. The chemical changes take place within an enormous blast furnace. A furnace like the one in Fig. 132 may be 80 feet high, and its greatest diameter may be 20 feet. Such a furnace will use in one day nearly 1200 tons of ore, 600 tons of coke, 300 tons of limestone, and 2400 tons of air. With these 4500 tons of material one furnace may make 600 tons of pig iron. As a means of comparison consider the large railway locomotives used for passenger service. The largest one weighs only a little more than 300 tons. One blast furnace will make in one day nearly enough iron for two large railway locomotives. In addition to 600 tons of iron the furnace will produce as waste 400 tons of dust and slag and about 3500 tons of gases. To keep the temperature under control and to wash the dust from escaping gases some 18,000 tons of water will be required.

To meet modern demands production of iron is on a large scale



Scientific American

FIG. 132. The Process of Separating Iron from Iron Ore is one of Chemical Changes on a Large Scale

The figure shows a cross section through a modern blast furnace. Can you trace the process of making iron in this furnace?

The melting point of iron is about 1530° C. Since iron from the ore flows away from the furnace as liquid, the temperature within the furnace must be higher than the melting point of the metal; that is, it must be more than 1530° C. It is obvious that an enormous amount of heat energy is used in making pig iron. As you may see, about 1 ton of coke is required to make 1 ton of iron. The amount of coke used in one furnace in 24 hours (600 tons) is sufficient to pull the heaviest passenger train six times over the distance between New York and Chicago.

Now let us go back to the chemistry of the process. We have said that iron (Fe) must be separated from iron oxide (Fe_2O_3), and that in addition the iron must be separated from the earthy material with which the ore is mixed.

You will recall that coke and limestone are put into the blast furnace with the ore. Carbon in the coke takes part in the chemical change which separates iron from oxygen. Limestone takes part in the chemical change which separates the earthy material from the metal; it acts chemically upon it, producing a glasslike substance called slag. Probably you would like to see all these substances. Maybe you can get from one of the steel companies samples of coke, limestone, slag, and pig iron. Arrange these as a display to show the materials that are put into the blast furnace and the materials that come out.

The processes taking place within a blast furnace represent chemistry on a large scale

The interior of a blast furnace is shown in Fig. 132. Ore, coke, and limestone are fed in through the top. A strong blast of hot air is forced in at the bottom and upward through the mixture. Iron is drawn off as liquid (melted) through an opening near the bottom of the furnace. Slag is drawn off through an opening a little above the one through which iron is drawn. Gases escape through a pipe near the top. The process is continuous. As iron and slag are removed more ore, coke, and limestone are added. In 24 hours 2100 tons of solid matter and 2400 tons of gases enter the furnace. In this same interval 1000 tons of solid matter and 3500 tons of gases leave the furnace. Notice that 1100 tons of material placed in the furnace as solid matter leave the furnace in the form of gases.

Now let us put these changes into chemical language. The first chemical change is a simple one. Coke burns in the blast furnace just as in any other furnace. As the incoming hot air strikes the mass of burning coke, at the bottom of the furnace, carbon, of which the coke is composed, combines with oxygen and forms carbon dioxide. This is shown by the expression, called an equation,

Many chemical changes take place in the extraction of iron from iron ore

$$\underset{\text{carbon}}{C} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\substack{\text{carbon}\\\text{dioxide}}}{CO_2}$$

The hot carbon dioxide is then forced upward through the hot coke.

At a higher level in the furnace a second chemical change takes place as the carbon dioxide and the hot carbon (coke) act upon each other and form carbon monoxide, thus:

$$\underset{\substack{\text{carbon}\\\text{dioxide}}}{CO_2} + \underset{\text{carbon}}{C} \longrightarrow \underset{\substack{\text{carbon}\\\text{monoxide}}}{2\,CO}$$

This carbon monoxide is the same poisonous gas formed within the cylinders of an automobile. It is always formed when there is too much carbon and not enough oxygen (air) for complete burning. Molecules of carbon monoxide move upward through the mixture containing the ore. Remember that the temperature within the furnace is higher than the melting point of iron.

Under these conditions there is a third chemical change at a still higher level. There is chemical action between the carbon monoxide and the iron oxide (ore). In this change iron is produced.

$$\underset{\text{iron oxide}}{Fe_2O_3} + \underset{\substack{\text{carbon}\\\text{monoxide}}}{3\,CO} \longrightarrow \underset{\text{iron}}{2\,Fe} + \underset{\substack{\text{carbon}\\\text{dioxide}}}{3\,CO_2}$$

As this iron is formed it flows as liquid toward the bottom of the furnace.

Then there is the chemical change that converts the earthy material (mostly silica) into slag. Calcium carbonate (limestone) and silicon dioxide (silica) act together to form calcium silicate.

$$\underset{\substack{\text{calcium}\\\text{carbonate}}}{CaCO_3} + \underset{\substack{\text{silicon}\\\text{dioxide}}}{SiO_2} \longrightarrow \underset{\substack{\text{calcium}\\\text{silicate}}}{CaSiO_3} + \underset{\substack{\text{carbon}\\\text{dioxide}}}{CO_2}$$

The slag is chiefly calcium silicate, similar to ordinary glass. The molten slag, like the molten iron, flows toward the bottom of the furnace.

These two hot liquids may be compared with oil and water — they do not mix. Slag (density about 2.5) is less

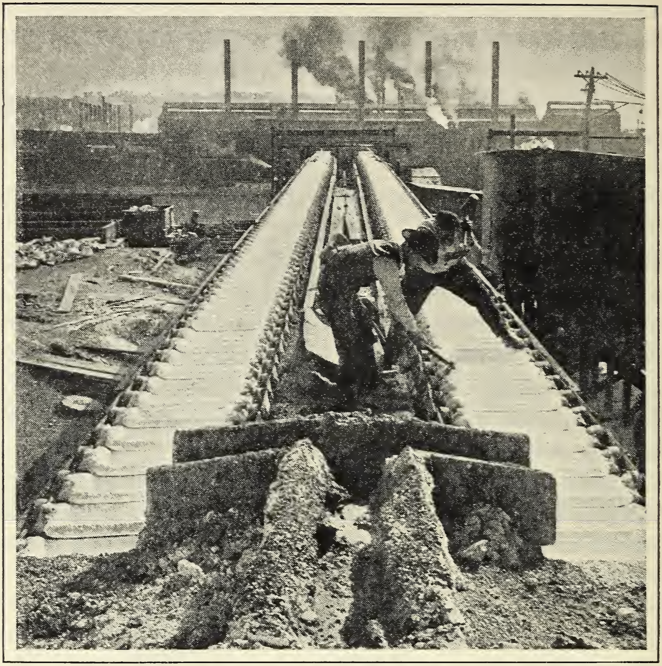


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Fig. 133. The Molten Iron as it comes from the Blast Furnace is often allowed to run off into Molds

When cooled it forms blocks, or "pigs," of iron, which can be moved as needed

dense than iron (density about 9) and so floats on top of it. Slag is drawn off through one opening, as we have seen (Fig. 132), and iron through another. The slag is not used and must therefore be removed as waste. The liquid iron may be run into molds, where it hardens to form cast iron. Because the iron in the molds is supposed to look like little pigs, it is commonly called pig iron (Fig. 133). Very frequently the iron is not made into "pigs." It may be transferred immediately (as liquid iron) to another furnace to be made into steel.

D. What is Cast Iron, and How is it Used?

Only a small amount of the product of the blast furnace is used as cast iron. If you will examine some of it you will see why.

Because of the impurities in cast iron it does not meet the demands of the modern Machine Age

Cast iron contains some carbon. This element will dissolve in melted iron somewhat as salt dissolves in water. It contains some silicon, formed in the furnace from silicon dioxide, which also dissolves in melted iron. It contains other impurities, including at least traces of sulfur and phosphorus. These properties of cast iron make it less widely useful than wrought iron or steel, which we shall discuss presently. Cast iron is hard and brittle. It cannot be shaped by hammering, for when struck with a hammer it may break. If you have a lid from a useless old stove or a piece of a worthless iron kettle, strike it a sharp blow with a hammer. It will be obvious to you that cast iron would not be satisfactory for use as automobile axles or for bridges. It is suitable only for making castings, and so it has very limited usage.

Iron castings are made for iron kettles and pans, and for pieces of stoves and furnaces, although even for these articles cast steel is commonly used. A mold is prepared of the desired shape, and molten iron from the blast furnace is poured into the mold and allowed to harden, as we saw in an earlier paragraph.

In the process of making wrought iron from cast iron some of the impurities are removed

Now let us look at wrought iron. How is iron from the blast furnace made into wrought iron? Wrought iron is nearly pure iron. *Wrought* means "worked." As iron cools, it passes through a condition in which it is soft and easy to mold. In the early days ironworkers worked this soft iron from the crude blast furnaces by hammering it. The impurities, including carbon and silicon, were worked out to the surface and thus removed.

Obviously, the process of working iron with heavy steel hammers not only required severe muscular labor but was very slow.

Today wrought iron is made by a simpler process. Molten iron from the blast furnace is run into a second furnace, where hot air is forced through it. In this manner carbon and most of the other impurities are burned out of it. In spite of the fact that wrought iron can be made more easily today, it is not widely used. Ironworkers have learned to make at less cost a soft steel which is an excellent, if not a better, substitute.

E. How is Iron from the Blast Furnace made into Steel?

The first step in the manufacture of steel is similar to the process for working wrought iron: impurities are burned out of the cast iron. Then substances are added to the molten iron that will impart to it the properties desired in the steel.

In the process of steel-making, impurities are removed from the molten iron

There are two main processes for making steel, and the process to be used must be determined by the nature of the impurities in the iron. Compounds of phosphorus and sulfur are extremely objectionable as impurities, for their presence makes steel brittle. If compounds of these elements are present, the basic open-hearth process is used. There are, on the other hand, some ores that have almost none of these objectionable impurities. If iron is derived from ore that is free from sulfur and phosphorus, it may be made into steel by the acid Bessemer process. In either process the steps are about the same.

In the acid Bessemer process the furnace, called a converter, is shaped somewhat like a huge bottle (Fig. 134). One furnace will hold about twenty-five tons of iron. It is mounted on an axle so that it may be tipped to one side for

Fig. 134. In the Bessemer Process for Steel-Making, Molten Iron is poured into a Converter

A blast of air is forced through the molten iron, and the impurities are burned out as shown above

filling and to the other side for emptying. Iron is poured in, hot air is forced through it, and steel is poured out.

Picture the process. White-hot iron from the blast furnace is poured into the converter, which is tipped to one side to receive it. The converter is then returned to an upright position. A blast of air which is forced in from the bottom passes upward through the hot metal. The impurities in the iron, carbon and silicon, are burned out in about twenty minutes. The air blast is then shut off, and while the iron is still liquid the substances to be added are carefully measured and put into it. For one common form

of steel these substances are carbon and manganese, in a form known as *spiegeleisen* (a German word meaning "glass iron").

Does this seem as if the process for making steel is a process of removing carbon and then adding it? In a way this is true. The composition of steel must be carefully controlled if steel is to have the desired properties. It must have neither too much nor too little carbon. The surest way of accomplishing this is the method just described; for it is easier to add the necessary amount of carbon to pure iron than it is to reduce the amount of carbon in cast iron to just the right quantity.

Workers in steel have learned to make steel for many different purposes. Steel for knife blades is not the same as steel for watch springs; neither is it like the steel for steel rails. Steel for knife blades must hold an edge, and it should be a steel that will not rust. A steel containing some 12 per cent of chromium is used for knife blades. Since these properties are of no importance in steel rails, a cheaper grade of steel is used for rails.

F. What Chemical Change takes place as Iron Rusts?

The chemical change that takes place as iron rusts is in a sense the opposite of the change that takes place as iron is made from iron ore. Iron ore, as you have seen, is iron combined with oxygen. In the blast furnace the iron is separated from the oxide in chemical changes already described. But when iron rusts it is combining again with oxygen, forming a compound similar to the ore from which it was made. The general nature of the change may be shown by the following equation:

The chemical process by which iron is made from iron ore is in a sense opposite to the one which takes place in rusting

$$4\,Fe + 3O_2 \longrightarrow 2\,Fe_2O_3$$

Notice that we say "general nature of the change." The complete change is more complex.

How may iron structures be protected from rust? The answer is, by preventing oxygen from getting to them. Painting iron is the most obvious method of doing this.

Mention has already been made of steels that do not rust. These are the "stainless" or rustproof steels used for cutlery. They are not strictly rustproof, although under ordinary conditions of use they are nearly so. All the iron that we use goes, sooner or later, through the same course of changes, which begin as it is separated from iron oxide, and end when it becomes again iron oxide. Is Fig. 135 a familiar one? It illustrates one step in the cycle of changes. Iron ore has been deposited at various places upon the earth. It is mined and used in manufacture. In time it rusts. Ironworkers estimate that in the whole world 29,000,000 tons of iron rust away every year. What happens to this rust? Will natural forces sort it out again as ore for future races of man? As we think over the nature of the changes required for re-sorting, and as we recognize the many hundred millions of years required for our present ore beds to form, we are inclined to say that iron changed to rust is lost forever.

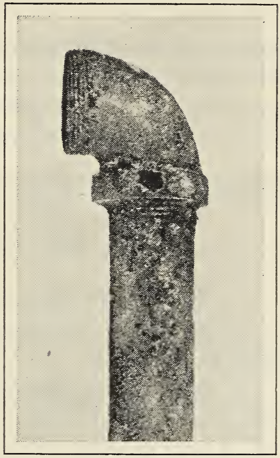


Fig. 135. Rusting is One Part of a Cycle which makes Iron from Iron Oxide and then turns it back into Iron Oxide

And now in conclusion let us recall our opening to this chapter. We referred to our present age as the Age of Iron and the Age of Power. We may call it also the Age of Steel. Perhaps some figures will make this statement more impressive. In 1929 some 82,000,000 tons (short tons) of iron ore, or enough to fill a 750-foot hollow cube, were

mined in the United States. Most of it was mined in Minnesota and Michigan. It was loaded on boats and shipped over the Great Lakes to Gary, Cleveland, Buffalo, and other cities where iron and steel mills are located. This quantity of ore became some 40,000,000 tons of iron, and flowed away from the blast furnaces to be made into steel.

Iron and steel are important materials in this present Age of Power. Man's use of these materials has come from the discovery of their origin and of the processes by which they may be changed into usable form.

Can You Answer these Questions?

1. Why is iron cheaper than aluminum?

2. Name the four elements that make up 87 per cent of the crust of the earth.

3. What are the chief differences between cast iron, wrought iron, and steel? How do these differences affect the purpose for which each of these metals may be used?

4. How may one by definition distinguish between an ore, a mineral, and a metal?

5. How do minerals differ from each other?

6. What is the relationship between the density of certain minerals and their tendency to be deposited in one place?

7. How are minerals sorted into deposits?

8. What is meant by the double concentration of ores?

9. What are some of the main steps in the process of changing hematite ore into iron?

10. Why are limestone and coke used in a blast furnace?

11. Why should slag float on molten iron?

12. What differences are there in the magnetic properties of soft iron and steel?

13. What reasons are there why steel is superior to cast iron?

14. Is it correct to say that the chemical change in rust is in a sense opposite to the change that takes place as iron is made from iron ore? Why?

Questions for Discussion

1. Are all minerals found as ores? Do all metals come from ores?

2. Do you think that, if the processes for refining iron and steel had not been found, possibly some other metals might form the basis of our Machine Age? Which ones?

3. As time goes on, what becomes of the iron that rusts away in the dump heap?

4. Do you think that any machine-made steel things are just as artistic as were handmade wrought-iron things?

Here are Some Things You May Want to Do

1. What do you know about precious stones, such as diamonds, emeralds, or rubies? Are they minerals? Are they found in ores? What is the process by which they are formed in the earth? Make a special study of precious stones and tell about them in class.

2. If you do not already have a collection of rocks, minerals, and ores in your school museum, you might wish to prepare such an exhibit now. You would of course begin with those found in your immediate vicinity. Include ores of each of the common metals. If you have friends in other cities, ask them to help you by sending specimens peculiar to their own environment.

3. Compare the properties of hematite and magnetite. Test the two ores with a magnet to learn why one is called magnetite.

4. Place a small wad of steel wool in a test tube and turn the tube upside down over water. Why does water rise in the test tube?

5. Place some small steel tacks in a test tube and add hydrochloric acid to cover them to a depth of about one inch. What happens to the tacks? What is the origin of little particles of carbon that collect on top of the liquid?

Chapter XII · What determines the Usefulness of Metals?

You have learned in your previous science work that there are ninety-two known chemical elements. Of these ninety-two elements you may be interested to know that at least thirty-nine are metals. You are more familiar with some of these metals than with others. As a result of your reading in the last chapter you should know a great deal about one of them, iron. How many others can you name?

Iron is the most used of all metals

Of all these metals iron is used in greatest abundance. In one year the quantity of iron used is, in fact, something like thirty times that of all the other metals taken together. Why do we use so much iron? You should be able to answer this question. In the first place, the ores from which the metals are to be secured must be deposited in such a way as to make them readily obtainable and in such condition as to make them easily workable. In the second place, processes must be known for the extraction of the metal from the ore. Iron satisfies both of these requirements.

The extent of ore deposits and the ease of extraction help to determine the usefulness of metals

The importance of these two factors may be seen if you will contrast iron with aluminum. The latter, as you may know, is more common in the crust of the earth, and yet iron is used far more widely. The reason for this is that the substances from which aluminum may be profitably extracted are not found concentrated, or brought together, in large deposits. Aluminum ore is not as plentiful as iron ore. Besides, the process for separating aluminum requires more energy than the process for separating iron. Consequently, even though aluminum is more abundant in the crust of the earth, the metal itself is much more expensive than iron.

When we say that we live in a civilization built upon the use of iron, we do not mean that no other metal is used. In the search for better things other metals are very important. The electrical industries use copper, lead, and zinc. The canning industries use tin. The paint industries use lead and zinc. You can doubtless think of other industries and other uses of metal. But it is doubtful whether you can name uses for all the thirty-nine metals among the ninety-two elements. Let us see what we can find out about the properties of some of these other metals.

A. How do Metals differ in Chemical Activity?

Compounds of calcium are next to iron in abundance in the crust of the earth. Sodium, potassium, and magnesium follow calcium in order of abundance. Probably you have never seen any of these as metals, but you have often seen compounds of them. Marble is calcium carbonate ($CaCO_3$). Ordinary table salt is sodium chloride ($NaCl$). Compounds of these metals are soluble in water, and since they are abundant, you may expect to find them dissolved in ocean water. Most of the salt of the ocean is, in fact, a mixture of compounds of these four metals.

But why is it that you seldom see these metals as elements? You can guess a part of the answer. They may be separated from their compounds only by the use of a large amount of energy, and are thus expensive. There is another reason. They have no important uses. While this is partly due to their expensiveness, it is also due to certain peculiar properties they possess. Because of these properties it is said that these metallic elements are very active. Perhaps this can best be explained through some experiments.

Abundance and properties are factors determining usefulness of metals

If there is a chemical laboratory, or workroom, in your school you may be able to get from it some samples of

these metals. What strange-looking metals they are! Your science teacher will warn you that you must not handle sodium or potassium in your fingers. These metals enter vigorously into chemical action with water, and there is enough moisture on your fingers to cause them to react and produce bad burns. For this reason they must be handled with a pair of forceps. The metals are kept for use under kerosene, for there is no chemical action between them and kerosene, and the kerosene serves as a protection from air and water.

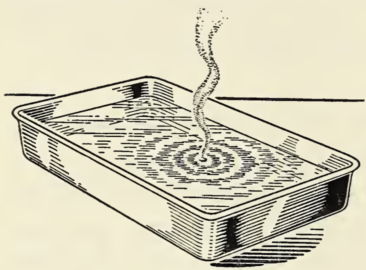


Fig. 136. There is a Rapid Release of Energy when Sodium is brought into Contact with Water

With a pair of forceps lift a piece of sodium from the jar in which it is kept. The metal is soft and easily cut with a knife. Cut a piece no larger than a grain of wheat. Holding it at arm's length with the forceps, drop the small bit of sodium into a dish of water. Since sodium is less dense than water, it will float on the surface. Notice that chemical action begins immediately between the sodium and the water. There is a rapid release of energy, as shown in Fig. 136. Enough heat is produced to melt the metal. It runs about over the surface of the water, growing smaller and smaller until it finally disappears. At the same time gas, which may be identified as hydrogen, is released by the chemical action. The sodium disappears, becoming part of a chemical compound, and this compound dissolves in the water. If you wish to separate the compound, you may do so by evaporating the water. The compound, sodium hydroxide, will be left in the dish as a white solid.

Some metals are very active in their chemical reactions

Potassium resembles sodium. It is soft, easily cut with

a knife, and reacts with water even more vigorously than sodium. Try it, but remember! Both of these elements must be handled with extreme care. Never pick them up with your fingers; always use a pair of forceps. Take a very small piece for your experiment. Never stand near the dish when you drop the metal into the water.

Calcium reacts with water in a similar manner, but much less vigorously. Try this experiment too. You need have no fear of holding calcium in your fingers. It is much harder than sodium and must be cut with a chisel or a saw. Calcium is denser than water, and so sinks. Hydrogen is slowly released in bubbles that rise to the surface as chemical action goes on between the metal and the water.

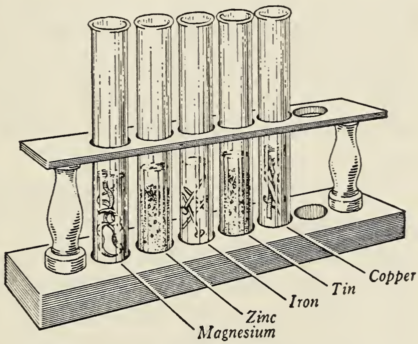


FIG. 137. Some Metals are Less Active in Chemical Changes than Others

What results did you get from your experiments?

Magnesium is also a chemically active metal, but less active than calcium. While it does not react rapidly with water it does react vigorously with oxygen. This metal is supplied to the laboratory in the form of long strips rolled into a coil. In this form it is called magnesium ribbon. Hold a short strip of magnesium ribbon in a pair of forceps and apply a match to it. The metal will burn furiously, producing an intensely bright light. On account of the brightness of the flame magnesium is sometimes used as a light for signaling. Such a flame may also be used to light the surface of the ground for forced landing of airplanes at night. Powdered magnesium is used in flash-light powder.

To test the chemical activity of metals less active than

calcium, use acid instead of water. Place in each of five test tubes a little dilute hydrochloric acid. Arrange the tubes in a rack, as shown in Fig. 137. In one of the tubes place a small piece of magnesium, in the second a piece of zinc, in the third a piece of iron, in the fourth some tin, and in the fifth some copper. Which shows most and which shows least violent chemical action?

While the chemical action is in progress bubbles of hydrogen escape from liquid in the tubes containing magnesium, zinc, iron, and tin. If you bring a match to the mouth of the test tube, you may see that this gas will burn. Magnesium, zinc, iron, and tin, as well as some other metals, react with acid and produce hydrogen. In the tube containing copper and hydrochloric acid there is no evidence of chemical action.

Our experiments show a striking contrast between sodium or potassium and copper. Sodium reacts vigorously with water, and copper does not react even with acid. If we should test silver, gold, and platinum, we should find that they show even less chemical activity than copper. Gold and platinum do not rust or become dull in air even when heated. The other metals may be arranged in order of chemical activity between these extremes.

The usefulness of a metal may be determined in part by its durability when subjected to chemical substances

From these experiments you might decide that one way to determine the usefulness of a metal is to test its chemical activity when subjected to acids or other chemical substances. This conclusion would be correct. But do not draw further conclusions which might seem to follow. If, for example, you said that a metal increases in usefulness as its chemical activity decreases, you would be wrong. In fact, one of the most important phenomena in our everyday life may be produced by chemical action, and this in turn depends upon the chemical activity of certain metals. These simple chemical changes are really very important. Let us explain this.

B. How is Electricity produced by Chemical Action?

Let us begin by trying some experiments. First secure some strips of zinc, tin, and copper. Then put some dilute acid into a glass tumbler. You may use either hydrochloric of sulfuric acid, but hydrochloric is better in these simple experiments, for it does not burn your clothing or your fingers so badly if you happen to spill it. Be careful, however, whichever acid you use, to keep it off your hands and your clothing.

Place a strip of zinc in the acid. Is there evidence of chemical action? Do the same with a strip of tin, and then with a strip of copper. Notice that zinc in acid shows evidence of chemical action. Tin shows some action, but less than zinc. Copper shows no action.

Electricity is released from chemical action between a metal and an acid

Now join a strip of zinc and a strip of copper by means of a short piece of copper wire. For convenience you may use strips with binding posts attached. Support them as shown in Fig. 138. Place the strips joined by the wire in the acid, as shown in Fig. 138, *A*. Watch carefully and notice that there is now evidence of chemical action on both the zinc and the copper. Now disconnect the wire joining the two strips. Is there still evidence of chemical action on the copper? Is there chemical action on the zinc? Clearly the observations are not the same after the wire joining the two strips has been removed, as you can see from Fig. 138, *B*. Bubbles of gas rise from the surface of the copper only while it is joined to the zinc. You see evidence that energy is released by chemical action between the zinc and the acid. Some of the energy flows along the wire from the zinc to the copper. The evidence of this flow is in the fact that chemical action shows on the copper while it is joined to the zinc, and that it does not show on the copper after it is separated from the zinc. The energy that flows along a wire is electrical energy. This is produced by

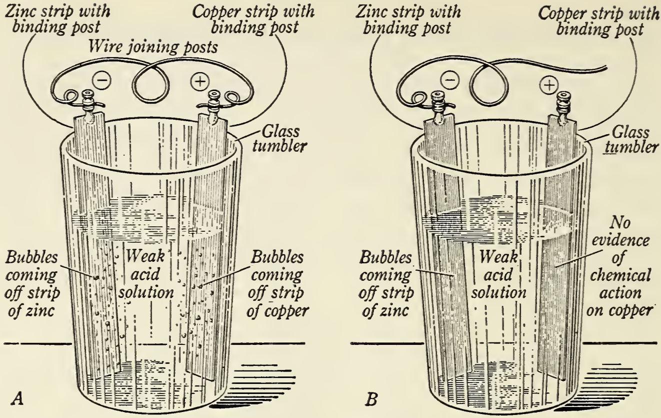


Fig. 138. Electricity may be produced by Chemical Action

A, when the zinc and copper strips are joined, there is evidence of chemical action on both strips; *B*, when the wire is removed, only the zinc shows evidence of chemical action. The wire acts as a conductor

chemical action between zinc and acid. When the strip of zinc is joined with a wire to a strip of copper as shown in Fig. 138, *A*, there is a flow of electricity along the wire.

How may we explain these observations? Doubtless you already know something of the electron theory. Let us recall it for you. The theory supposes that atoms are composed of electrons and protons. Protons are particles, or bits of substance, charged with positive electricity, and electrons are negative particles. An atom is composed of an equal number of electrons and protons. The atom is therefore neither positive nor negative. It is neutral.

In chemical changes some atoms may lose electrons and some atoms may gain electrons. The particle which remains after the loss of an electron carries a positive charge. (Neutral, or zero, minus negative equals positive.) The positive particle formed from the atom in the chemical change may be called a positive ion. The particle that is formed after the gain of an electron carries a negative

Electricity from chemical action may be explained by the use of the electron theory

charge. (Neutral, or zero, plus negative equals negative.) The negative particle formed from the atom may be called a negative ion.

Now you may explain the observations of chemical action between zinc and hydrochloric acid in the following way:

Hydrochloric acid is hydrogen chloride dissolved in water. Hydrogen chloride is a compound of two elements, hydrogen and chlorine. Its formula is HCl. You know that the element hydrogen is a gas. So is chlorine. Under certain conditions these two elements will combine and form hydrogen chloride. This compound, also a gas, is very soluble in water.

In the chemical change in which a molecule of hydrogen chloride is formed, a hydrogen atom loses an electron and a chlorine atom gains an electron. As hydrogen chloride dissolves in water it forms a solution, hydrochloric acid, containing hydrogen ions and chlorine ions. We may use the symbol, or sign, H^+ to represent the hydrogen ion and the symbol Cl^- to represent the chlorine ion.

What happens when a strip of zinc is put into such a solution containing hydrogen and chlorine ions? From observation we have learned that zinc dissolves and that hydrogen is released and escapes as gas. In other words, zinc enters the solution and hydrogen comes out of the solution. The zinc atoms lose electrons, passing into solution as zinc ions. The hydrogen ions gain these electrons, becoming hydrogen atoms.

Careful study has led chemists to suppose that one atom of zinc loses two electrons as it changes to an ion. The symbol for the zinc ion is therefore Zn^{++}. According to the electron theory the change occurring as zinc reacts with hydrochloric acid may be represented as follows:

$$\underset{\text{zinc atom}}{Zn^\circ} \longrightarrow \underset{\text{zinc ion}}{Zn^{++}} + 2 \text{ electrons}$$

$$\underset{\substack{\text{hydrogen}\\\text{ions}}}{2\,H^+} + 2 \text{ electrons} \longrightarrow \underset{\substack{\text{hydrogen}\\\text{atoms}}}{2\,H^\circ}$$

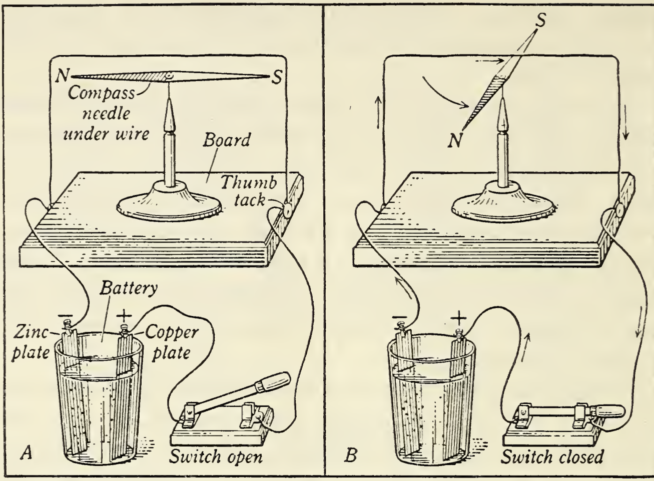


FIG. 139. A Wire carrying a Current shows Magnetic Properties

In *A* the switch is open; the wire and compass needle are parallel. Notice in *B* the position of the compass needle when the switch is closed

Two atoms of hydrogen then unite to form a molecule ($2\ H \longrightarrow H_2$) and the molecules escape from the surface.

Electricity is, in theory, a flow of electrons

Return now to the observations of chemical action on the strips of copper and zinc as they were used in the apparatus shown in Fig. 138. There is evidence of chemical action on the zinc and on the copper when the two strips are joined by a wire. There is evidence of chemical action on the zinc but no evidence of chemical action on the copper after the connecting wire has been removed. Obviously the wire has something to do with the action at the copper strip in the first case.

You may explain this observation if you suppose that some of the electrons released from the zinc atoms flow along the wire from the zinc plate toward the copper plate. A current of electricity is such a flow of electrons along a wire. The chemical change on the copper strip is the action

of these electrons on hydrogen ions. The electrons have been driven to the surface of the copper by chemical action on the zinc. Hydrogen atoms and then hydrogen molecules are there formed as shown in the equations just given.

You may be able to get further evidence that electricity will flow along a wire from zinc toward copper when strips of these metals so connected are put into acid. Place a compass close to the wire as shown in Fig. 139 and arrange it so that the wire and the magnetic needle of the compass are parallel before the two strips are connected. When you connect the plates you may see an effect on the needle. Such a magnetic effect is produced whenever a stream of electrons (a current of electricity) is flowing through a wire.

For further experimenting substitute a strip of tin for a strip of zinc. There is evidence of chemical action between tin and acid, but you must observe closely to see it. Electrons are given up by tin just as by zinc, except that with tin the action is much slower. A sensitive galvanometer, however, would give evidence of a flow of electrons along the wire from tin to copper.

These experiments show that some metals are more active than others with hydrochloric acid. You have evidence that tin is less active than zinc, but more active than copper. You also know that calcium is more active than magnesium in its action with water. Aluminum, another familiar metal, is less active than magnesium, but more active than zinc. An arrangement of common metals in order of their activity is as follows:

potassium	aluminum	lead	platinum
calcium	zinc	copper	gold
sodium	iron	mercury	
magnesium	tin	silver	

In terms of the electron theory all free metals lose electrons in these chemical changes where a metal takes the place of hydrogen in water or an acid. The least active

metals do not form compounds when exposed to air and water. The active metals form compounds when exposed to air and water. It is difficult to separate active metals from their compounds. The less active metals are easily separated from their compounds. It is easier, for example, to separate copper from oxygen than it is to separate iron from oxygen. It is easiest to separate gold and platinum from their compounds. It is most difficult to separate potassium, calcium, and sodium.

Metals differ in their chemical activity

All the metals and their compounds have different properties. These properties determine how the metals shall be used. Zinc, for example, is used in the manufacture of dry cells. Other metals could be used but no other metal is so satisfactory. Lead is used for storage batteries, copper is used as a conductor of electricity, silver is used for coins, and so on. In each case the particular property of a metal together with its relative abundance determines how a metal shall be used. You may learn more about the relations of uses and properties as you continue your study of materials.

The usefulness of metals is determined by their properties.

Can You Answer these Questions?

1. Why, if aluminum is more common than iron in the crust of the earth, do we use more iron in industry?

2. What are two good reasons why some metals are more expensive than others?

3. Why is magnesium used in flash-light powder?

4. Can you give some examples to show that the usefulness of a metal is determined by its chemical activity?

5. What are the main suppositions of the electron theory?

6. What is an ion? What part does an ion play in the production of electricity by chemical action? When is an ion positive? When is an ion negative?

7. Can you give a simple definition of current electricity?

8. How may the differences in the activity of elements in chemical changes be explained in terms of the electron theory?

9. Why is an atom neither positive nor negative?

10. Why do bubbles form on the copper strip illustrated in Fig. 138 only when the zinc and copper are joined with a wire?

Questions for Discussion

1. Which are found free in nature, the active metals or the less active metals? Why?

2. Can you give any examples which will support the statement that man adapts himself to the resources which the environment provides?

3. Is there any reason why the flow of electricity along a wire might not as well be from copper to zinc as from zinc to copper?

4. Why should it be easier to separate gold and platinum from compounds than to separate potassium and sodium? Remember that the latter are among the more active metals.

Here are Some Things You May Want to Do

1. See if you can find any uses which are being made of some of the less abundant elements. Krypton and xenon, for example, are used in colored lighting, and tungsten is used for electric-light filaments. What others can you find? Study vanadium, tellurium, thorium, and titanium. Use the encyclopedia.

2. Test various metals for their capacity to produce electricity. Take strips of different metals of the same size, a tumbler of acid, and a compass. How should you determine which of the metals has the greatest capacity for the production of electricity?

3. Substitute a strip of carbon for the strip of copper in the experiments described on pages 249–250. Use a compass or a galvanometer and determine which metal joined to carbon with a wire gives the strongest and which the weakest flow of electrons.

Chapter XIII · What are the Uses of Metals Other than Iron?

We have said that in one year the quantity of iron used is many times greater than the total quantity of all other metals put together. Yet the industries of today could not be carried on as they are with iron alone. A number of other metals have become necessary to the industries of our Machine Age. Perhaps you may secure some idea of the importance of some of these other metals by studying the table below, which shows the number of tons (short tons) of different metals produced in the United States during the year 1930.

Pig iron	33,493,996	Aluminum	114,517
Copper	697,200	Silver	2,119
Lead	573,740	Mercury	814
Zinc	489,361	Gold	96

The demand for other metals, such as copper and lead, has increased in this Machine and Electrical Age just as has the demand for iron. There was comparatively little use for copper before the days of the electrical industries. For example, only about seven hundred tons of copper were produced in 1850 in the United States. Chiefly because it is an excellent conductor of electric current, nearly 1400 times as much was produced in 1929. Likewise the demands for lead increased enormously after we learned how to make storage batteries. If all the metals produced in the United States in one year were brought together, what a tremendous pile it would be! Iron alone would make nearly a 600-foot cube. There would be enough copper for a 150-foot cube. Along with these immense cubes of iron and

The Iron Age depends to a great extent upon other metals

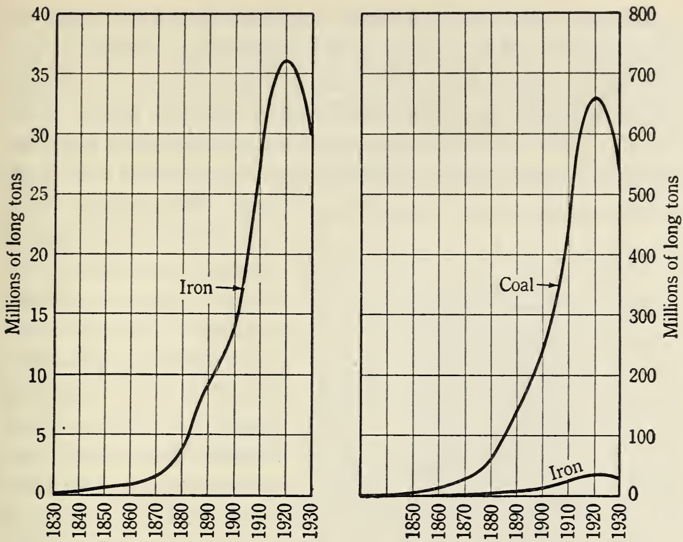


FIG. 140. The Demands for Coal and Petroleum have increased. The Charts show Production in the United States

copper there would be a 5-foot cube of pure gold. At the same time with the use of metals the demands for coal and petroleum have increased. The rate of increase in the demands for coal and petroleum and for metals since 1850 is shown in Figs. 140 and 141.

You already know something about the chemical activity of metals other than iron. You have also learned a little about how these other metals are used and why they are used as they are. Let us go into these last two matters at greater length.

A. What are Some of the Uses of Zinc?

Probably the most familiar use of zinc is for dry cells, a common source of electricity. Its chemical properties, which you have already studied, make zinc useful for this purpose.

Suppose you find out how a dry cell is made. Take the paper cover off an old dry cell. Directly beneath it you will find a metal can. This can is made of zinc. You may cut it down through the middle with a saw or a pair of old shears. Fig. 142 will help you to interpret what you see. Inside the zinc can is a layer of absorbent paper which has been thoroughly moistened with a solution of ammonium chloride. Inside the paper is a black mixture. This is composed chiefly of powdered charcoal and manganese dioxide. These substances also have been well moistened. The cell is not really dry, then. If it were it would be useless. Through the center is a carbon rod extending nearly to the bottom of the can. This rod does not quite touch the absorbent paper at the bottom of the cell. The can is sealed across the top with pitch or a similar substance. This holds the carbon rod in place. At the same time the evaporation of moisture is prevented. Pitch is a poor conductor of electricity; so electricity does not flow between the zinc and the carbon through the pitch.

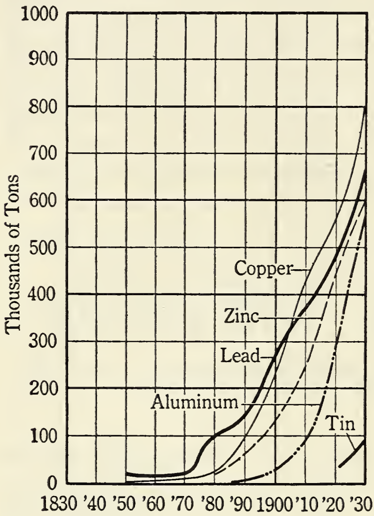


Fig. 141. This Chart shows Amount of Four Metals used in the United States from 1830 to 1930

You have already observed that zinc acts chemically with acid. We explained how zinc atoms lost electrons and became zinc ions. There is similar chemical action between zinc and ammonium chloride.

There are two binding posts on a dry cell. One is attached to the zinc and the other to the carbon. When these posts are joined with a wire, electricity flows along the wire. You may think of the flow of electricity as a flow of electrons from the zinc toward the carbon. Since electrons, or negative particles, flow from the zinc post, zinc is negative. Carbon is positive. When the posts are joined, chemical action between zinc and ammonium chloride goes on rapidly. After the connection between the two posts is broken so that electrons cannot flow away from the zinc, there is but little evidence of chemical action within the cell. If the cell is short-circuited, chemical action inside the cell soon destroys it.

Zinc is used in the manufacture of dry cells

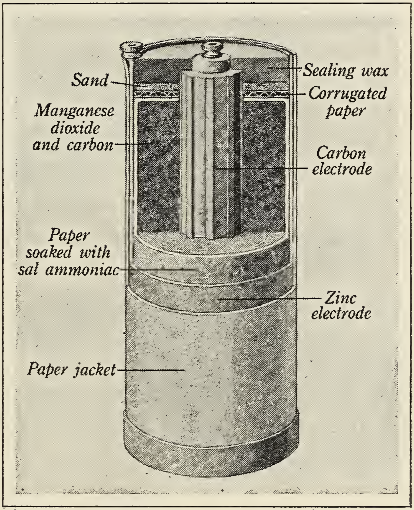


FIG. 142. Zinc is used in the Manufacture of Dry Cells

The fact that the metal zinc is a chemically active element makes it useful for dry cells. You observed magnesium to be more active than zinc. On that account wouldn't magnesium make even better dry cells than zinc? It probably would, but at present magnesium is too expensive to be used in this way.

Another use of zinc is for galvanizing iron. Galvanized iron is iron covered with a thin coating of zinc. More zinc is used for making galvanized iron than for any other

purpose. Water pails and garbage pails are made of galvanized iron. Sheet iron is usually galvanized, for zinc protects the iron from rusting. When zinc is exposed to air, a chemical change takes place, forming a thin layer of a zinc compound over the surface of the zinc. This chemical change is similar to the change that goes on when iron rusts. This compound of zinc, however, is different from iron rust in at least one important respect: it sticks fast to the surface over which it forms and protects the metal from further rusting, but iron rust scales off as it forms and leaves fresh surfaces of metal exposed to the air.

Zinc has many uses in modern life

Two compounds of zinc, namely zinc oxide (ZnO) and zinc sulfide (ZnS), are used in white paint. Zinc oxide is known to painters as zinc white. Zinc oxide is also used in the manufacture of rubber and in the manufacture of brass.

Deposits of zinc ore are neither numerous nor large. Then, too, the rate at which it is used in the United States (Fig. 142) has increased from about 23,000 tons in 1870 to more than 600,000 tons in 1929. Besides this, only about one eighth of the quantity used in industry is recovered for use again. What shall we do when there is no more? What do you think?

B. What are Some of the Uses of Lead, and Why is it Especially Satisfactory for these Purposes?

One of the most important uses of lead is in the form of lead plates in storage batteries used, for example, as a source of electricity in automobiles. A cross section of such a battery is shown in Fig. 143. If you could examine the plates of one of the cells in the battery, you would see that they are not alike. One is gray in appearance; the other is dark brown. The gray one is lead. The other is covered with a compound of lead known as lead peroxide (PbO_2).

Lead is used in storage batteries

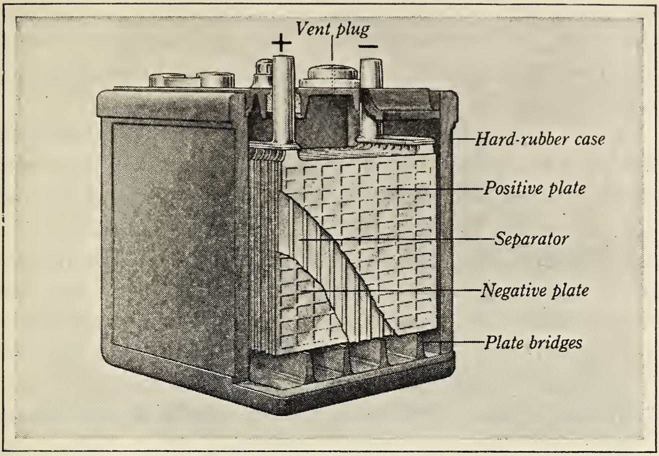


FIG. 143. Lead in the Form of Plates is used in a Storage Battery

The plates stand in a solution of sulfuric acid. When the binding posts on the plates are joined by a wire, electrons flow from the lead plate toward the lead peroxide plate. Chemical action between lead and sulfuric acid produces electrons, just as chemical action between zinc and acid produces electrons. Thus lead forms the negative plates in the discharging of a storage battery.

You know, of course, that a storage battery may be "recharged." The chemical change in charging is in a sense the reverse of the chemical change in discharging. Each cell is joined to a source of current in such a way that electrons are made to flow away from the positive plate to the negative plate. Electrons are forced back to the atoms on the negative plate. The cell may be repeatedly charged and discharged.

The operation of a storage battery is based upon the chemical activity of lead

Another form of lead in common use is a compound of lead called basic lead carbonate. It is used to a great extent in the manufacture of white paint. Painters know

this compound as white lead. In appearance it resembles zinc white. For reasons which you may learn from some experiments, zinc white is satisfactory for interior decorations while white lead is not.

In this experiment you will need some simple chemicals. Place a few small pieces of iron sulfide in a test tube that has been fitted with a one-hole rubber stopper and delivery tube, as shown in Fig. 144. In a second test tube place a quantity of zinc chloride (or zinc acetate or zinc nitrate) about equal in size to a grain of wheat. In a third test tube place a small bit of lead nitrate. Into the tube containing the compound of zinc pour water until the tube is half full. Do the same to the tube containing the compound of lead. Then place these tubes in a rack, as shown in the picture.

Pour into the test tube containing iron sulfide just enough water to cover the substance. Add an equal amount of dilute hydrochloric acid. The tube is now about one third full. Chemical action begins, and a foul-smelling gas starts to escape from the tube. Set the stopper with the delivery tube into the test tube and cause the gas to flow into the solution of zinc chloride. Fig. 144 shows how this is done. Now you see another chemical change. A white substance forms as the gas flows into the solution. Transfer the delivery tube so as to cause the gas to flow into the solution of lead nitrate. Again you see a chemical change. This time a black substance is formed.

How does all this show that zinc white is satisfactory for a decorative paint while white lead is not? The foul-smelling gas given off from the action of hydrochloric acid and iron sulfide is contained in coal smoke; it is a compound of hydrogen and sulfur, and is called hydrogen sulfide. What happened in your experiment when this hydrogen sulfide met the solution of zinc chloride? What happened when it met the solution of lead nitrate? What, then, would be likely to happen in homes where coal is burned, if white lead paint were used?

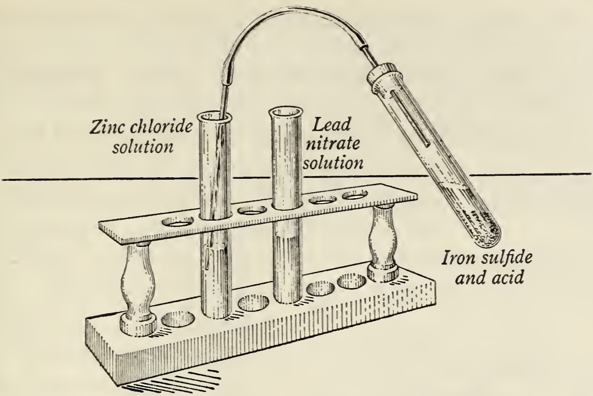


Fig. 144. Zinc White is Satisfactory for Interior Decorations, while White Lead is Not

Were the results of your experiment similar to those described in the text?

Another important use of lead is in the manufacture of lead pipe for plumbing. Lead is also used in the manufacture of several alloys. The type used in printing is made of an alloy of lead, tin, and antimony. Lead shot is made of an alloy of lead and arsenic. Solder and fuse wire are also lead alloys. Wood's metal is an alloy made of lead, tin, bismuth, and cadmium. The alloy melts at about 60° C. or 140° F. A spoon made of it would melt in hot soup or hot coffee. Such alloys of low melting point have some important uses.

Like zinc, lead is not found in abundance; and we are using it at the rapid rate of about 600,000 tons a year. Two hundred thousand tons go into paints and are lost. Of the 400,000 tons that go into manufactured articles only half will be recovered from the junk heap and used over again. Thus it is possible that a future civilization will find it necessary to use some other metal as a substitute for lead.

Is it likely that substitutes for lead will have to be found?

C. What are the Uses of Copper, and Why?

You know copper best as copper wire. Hundreds of thousands of miles of it are strung over the world for use in communication by telephone and telegraph and for conveying electrical energy for light, heat, and power. There are several reasons why copper is used for this purpose. It is one of the best conductors of electricity. It may be easily drawn into wire. It does not rust. And it is fairly abundant. Why wouldn't iron, for instance, or silver, do just as well? Iron is not nearly such a good conductor of electricity as is copper. Besides, it rusts. Silver is a better conductor than copper but is much too expensive for ordinary use as wire. When these considerations are taken into account, copper proves to be the most satisfactory metal to use in electrical circuits.

Copper is a good conductor of electricity

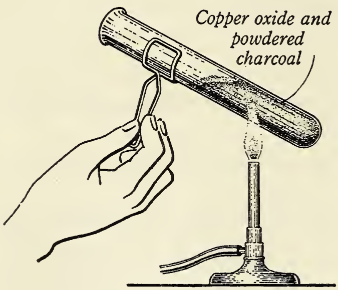


Fig. 145. It is Easy to separate Copper Oxide from Carbon

You will recall that copper is not active in chemical changes. Since it does not combine readily with other elements, it is often found in mines as free copper. It is found in this form in the mines of northern Michigan. These mines were worked by the Indians before Columbus discovered America. The most abundant ores, however, contain compounds of copper with oxygen or sulfur. It is easy to separate the metal. Would you like to try it and see?

Mix about equal parts of black copper oxide in the form of powder with finely powdered charcoal (carbon). Place the mixture in a test tube and heat over a flame, as in Fig. 145. Let it get very hot, and continue heating for two or three minutes. After it has cooled, pour the mixture

from the test tube onto a piece of white paper. Is there evidence that copper has been separated from the oxide? The chemical change may be shown by a simple equation:

$$\underset{\text{copper oxide}}{2\,CuO} + \underset{\text{carbon}}{C} \longrightarrow \underset{\text{copper}}{2\,Cu} + \underset{\text{carbon dioxide}}{CO_2}$$

Copper used in electrical industries must be pure. Copper wire containing as much as 0.8 per cent arsenic or 0.5 per cent silica offers more than three times as much resistance to the flow of electricity as wire that is free from these impurities. Nearly pure copper is prepared by a process of electrolysis. You may easily demonstrate the process in the laboratory.

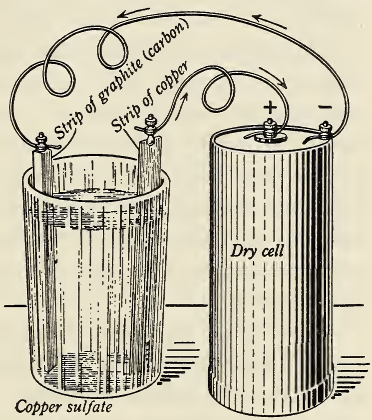


Fig. 146. Copper Plating is really a Form of Electrolysis

Your text explains what happens during the plating process

Set up apparatus, or equipment, like that in Fig. 146. Place in the tumbler a solution of copper sulfate and add a few drops of sulfuric acid to it. Set a strip of copper and a strip of carbon (in the form of graphite) in the solution and attach them to the terminals of a dry cell. The dry cell is attached so that the positive post of the cell (the one in the center) is attached to the copper and the negative post is attached to the carbon. Leave the dry cell connected in this manner for a few minutes and then take the carbon from the solution. What has happened? A plating of nearly pure copper has formed on the carbon rod.

This process of electrolysis is the same as the process used in electroplating. The carbon rod of our experiment

is electroplated. You may electroplate a knife blade if you set the blade in the solution (Fig. 146) in place of the carbon rod. Silver plating and gold plating are done in the same way as copper plating. In silver plating a strip of silver must be used in place of the copper, and a silver compound must be used in place of copper sulfate. For gold plating a strip of gold and a solution of a gold compound must be used.

Copper plating is really a form of electrolysis

The electron theory may again be used to explain the chemical changes that take place during electroplating and during the refining of copper. Molecules of copper sulfate ($CuSO_4$) in solution form copper ions (Cu^{++}) and sulfate ions (SO_4^{--}). The copper ion is an atom that has lost two electrons. The two negative charges on the sulfate ion indicate that it carries two extra electrons. The solution contains an equal number of these negative and positive ions.

What happens when the apparatus is set up as in Fig. 146? There is a flow of electrons in the direction indicated by the arrows in the drawing. Within the solution copper ions are moving about and bumping against the two plates. At the same time electrons from the dry cell are moving to the carbon plate. These electrons will combine with some of the copper ions and thus form copper atoms.

$$Cu^{++} + 2 \text{ electrons} \longrightarrow Cu^{\circ}$$

While electrons from the dry cell are moving toward the carbon, at the same time electrons are moving from the copper plate back to the dry cell. Atoms of copper in the copper plate are losing electrons and becoming ions:

$$Cu^{\circ} \longrightarrow Cu^{++} + 2 \text{ electrons}$$

As copper ions are formed they pass into solution.

The changes on the copper plate are in a sense opposite to the changes on the carbon plate. At the copper plate,

copper atoms lose electrons, leave the copper plate, and go into solution as copper ions. At the carbon plate, copper ions gain electrons, leave the solution, and deposit on the carbon as copper atoms. The changes from copper atoms to copper ions and from copper ions to copper atoms go on at the same rate. Electrical energy from the dry cell causes these chemical changes.

All the copper in the wires strung over the land has been purified, or refined, by a process like this one. In refining copper a large plate of the unpurified copper is used. Instead of carbon for the other pole a thin plate of previously purified copper is used. As described above, copper continuously goes into solution from the plate of impure copper. At the same time a deposit of pure copper is formed at the other pole. The impurities either do not go into solution or else are not deposited under the conditions of the electrolysis.

Copper has some important alloys. Brass is an alloy of copper and zinc. Bronze, as you know, is an alloy of copper and tin. One-cent pieces are made of bronze. Other coins are made of copper alloys. Our five-cent piece (nickel) is three fourths copper and one fourth nickel. Silver coin is 90 per cent silver and 10 per cent copper. Gold coin is 90 per cent gold and 10 per cent copper. Each alloy has properties that make it useful for particular purposes. The mixture of copper with gold and silver, for instance, makes these pure metals harder, and thus satisfactory for use as coin metal.

Under normal conditions we use copper in the United States at the rate of about 750,000 tons per year. Of this amount about one half is copper that has been previously used. The other half comes directly from the mines. Thus you see that the stock of copper, like the stocks of zinc and lead, is being rapidly reduced. It seems certain that at some time in the future substitutes for copper must be found.

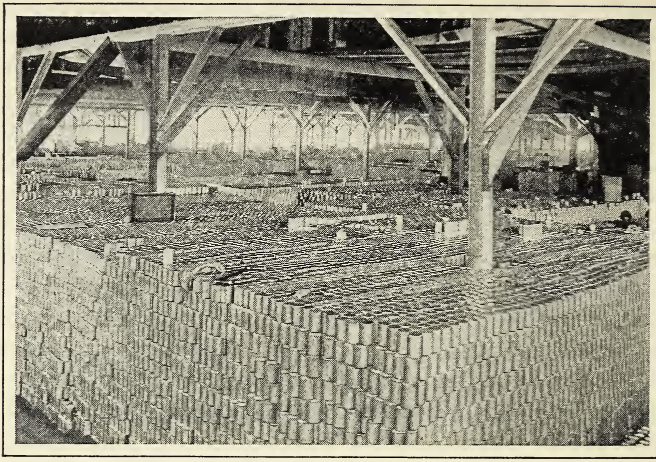


Fig. 147. Tin is largely used in the Canning Industries

Machinery even makes tin cans!

D. What are the Uses of Tin, and Why is it used for these Purposes?

You are most familiar with tin in tin cans, tinware used in the kitchen, and tin foil. But none of these articles really contains much tin. This metal is scarce and therefore expensive. Only very small deposits of tin have been found in North America. Most of the world's supply comes from the Malay Peninsula and the islands of the East Indies. Tin cans and tin kitchen utensils are mostly iron, with only a thin coating of tin. Iron coated with tin is known as tin plate. Tin foil is an alloy of lead and tin, in which there may be more lead than tin. As with other metals, the properties of tin determine its uses. This metal is more active in chemical changes than lead and copper, but less active than zinc and iron. It is useful as a coating for tin cans and kitchen utensils because it is not attacked by fruit or vegetable juices.

Tin is scarce and expensive

No important deposits of tin ore have been found in the United States; so we must import nearly all that we use. In fact, there are no large deposits known to exist anywhere in the world. Such supplies as are known are being rapidly used. In the United States we use annually about 90,000 tons of this metal. Of this more than one third is used for tin plate. Almost all of it is lost, as tin cans and other articles made from it are thrown away after they have been used.

E. What are the Uses of Aluminum, and Why is it used for these Purposes?

The extraction of aluminum depends upon electricity

Among the metals in common use today aluminum is a newcomer. The metal was first separated from one of its compounds about 1825, but only an extremely small amount was produced. As late as 1885 the metal was almost unknown outside chemical laboratories. During that year not more than three tons of the metal was produced in the whole world. Gold was much more abundant. During that same year the world production of gold was more than 200 tons. About 1886, however, a method was perfected by which aluminum could be prepared in large quantities. From then onward there has been a rapid increase in the rate of its production. This is shown in Fig. 141.

In the crust of the earth aluminum is the most abundant of all metals. It occurs in feldspar, the most abundant mineral on earth, to the extent of more than 10 per cent. It makes up more than 20 per cent of kaolin, the chief substance in common clay. But neither of these compounds is an ore of the metal, for no practical method has yet been worked out for separating aluminum from them. The ore from which we obtain aluminum is a form of aluminum oxide called bauxite (pronounced *bō′zīt*). It is not abundant like iron ore, but it is found in considerable quantities.

You have learned something about the methods used by primitive men to separate copper, iron, and tin from ore. Why didn't some early experimenter hit upon a method for doing the same thing with aluminum? One answer is that until recently there was no source of energy with which it could be done. Aluminum is a product of the electrical industries. Before the days of electricity there could be no aluminum.

The density of aluminum is less than that of many other metals

The striking feature about aluminum is its low density. Compare the density of a block of aluminum with the density of blocks of iron, lead, copper, and any other metal you may have. A block of aluminum weighing 340 grams was found by one class to have a volume of 125 cubic centimeters. That means that the density of aluminum is about 2.7 ($340 \div 125 = 2.72$). But a block of steel of 125 cubic centimeters was found to weigh about 960 grams. The density of steel is therefore about 7.7, nearly three times the density of aluminum. The low density of aluminum suggests uses which may be made of it.

An important measure of the usefulness of a metal for construction work, however, is its tensile strength. This is a measure of the force required to break by pulling, and is usually stated in pounds per square inch. The tensile strength of aluminum is about 35,000 pounds per square inch. In other words, a rod of 1 square inch in cross section will support a load of this amount. If the load is increased beyond this point, the rod will break.

The tensile strength of aluminum is low

The tensile strength of aluminum, unfortunately, is low compared with that of steel. One grade of steel, for instance, has a tensile strength of 460,000 pounds per square inch, more than thirteen times the tensile strength of aluminum. It is not strange, therefore, that experimenters among metal-workers have attempted to see what could be done about making alloys of aluminum with greater

tensile strength and at the same time no greater density. Their experiments have been fairly successful. Duralumin is an alloy of aluminum with small percentages of copper, magnesium, and manganese. Its density is less than 3. Magnalium is an alloy of aluminum and magnesium. Its density ranges between 2.0 and 2.5. The use of alloys such as these will certainly increase, for a change which reduces the weight of a material without reducing its strength is generally in the direction of improvement.

There are great opportunities in railroading as well as in automobiles, airplanes, and dirigibles for these less dense alloys. The average passenger train running between New York City and Chicago weighs about 850 tons. The engine alone weighs over 300 tons, and each car weighs about 80 tons. Such a train is made mostly of steel. What an enormous saving in fuel there might be if these trains could be made of aluminum alloy! Some new trains have been built of these new alloys. You will study them in more detail later, but you can secure some idea of the value of aluminum from the fact that one of these trains has a total weight, engine and all, of 80 tons, the weight of one car in the ordinary train. This train may be driven as fast as 110 miles per hour, and the cost to the passenger may be not more than one third the cost for travel at the present rate. This illustration is sufficient to suggest some of the changes that may come through the use of aluminum and its alloys.

Because of its low density aluminum is an important metal in modern engineering

We are using aluminum in the United States at the rate of about 550,000 tons per year (see Fig. 141). This is a small amount compared to the amount of iron that is used. With the rapid expansion of the use of airplanes and dirigibles, however, there will certainly come a rapid increase in the use of this metal. Along with this increase there will probably come an increase in the use of magnesium. For certain uses there seems to be great promise in alloys of these two metals.

The cost of aluminum today is considerably greater than the cost of steel. But as its use is extended the cost of production will certainly be reduced. Somebody may, and probably will, give us before long an efficient method for making aluminum from clay. Because of the abundance of the supply, it may be expected that this metal will, in large measure, take the place of iron and steel. In fact, there seems to be very good reason to think that we may shift gradually from an Age of Iron to an Age of Aluminum, just as at earlier times there were shifts from an Age of Stone to an Age of Bronze and from an Age of Bronze to an Age of Iron.

F. What about Other Metals?

These most familiar metals are by no means the only ones of importance to industry. On the contrary, some of the least familiar are very important. There is vanadium, for instance, only a few tenths of a per cent of which enormously increases the tensile strength of steel. Vanadium steel is used for automobile parts where great toughness is desired. Nickel and chromium in small quantities are used to increase the hardness of steel. They are contained in the steels used for armor plate. Copper, manganese, silicon, tungsten, and molybdenum are alloyed with iron in making different kinds of steel. As the percentage of these metals in the alloy is changed, the properties of the steel change.

Although scarce, many metals are valuable because of their importance in the manufacture of alloys

Probably two thousand alloys have been made and tested. When there arises a need for a metal with particular properties, someone tries to supply it. For instance, in the manufacture of bulbs for electric lighting there must be a lead-in wire to carry current to the filament, the thin thread within the bulb. This wire is sealed in glass; so the rate at which it expands and contracts as it is heated and cooled must

be equal to that of glass, else the glass will break. Platinum is an ideal metal for this wire, for it expands and contracts at the same rate as glass, but it is too scarce. After many experiments an alloy of nickel and iron was made which for this purpose was just as good as platinum. Because it is similar to platinum in this property it is called platinite. Again, one of the difficult problems in the manufacture of accurate clocks and watches was to make them keep accurate time both winter and summer. As the pendulum of a clock or the flywheel of a watch expands with warm weather, the timepiece runs slower. As it contracts in the cold weather, the watch or the clock runs faster. A metal that would neither expand nor contract was badly needed. Metal-workers found an alloy of nickel and iron called invar that meets this need. This alloy does expand and contract when heated and cooled, but by only one tenth as much as iron when the temperature change in both is the same.

Progress may be measured through the improvements made from one culture period to another

As men work with machinery they discover ways to improve the materials that go into it. Nothing is good enough. The automobile needs better springs, stronger axles, and more enduring paint. The airplane needs a stronger and lighter propeller, and metal that will better stand the effects of engine vibration. Railroads, lighting, radio, telephone, motion picture, and other developments are making constant demands for improvement. And yet the airplane of today seems pretty good in comparison with those of ten years ago. But so was the plane of ten years ago better than the one ten years earlier. May we expect the planes of ten years from now to be better than those of today? Unquestionably the answer is "yes." Among the most successful men of this generation are those who have made things better. So will it be in the next generation. What part will you play in the changes that are to come? As you look about for your

vocation, keep uppermost in your mind these questions: What needs to be done? What opportunities are there to make things better?

The increased use of iron has led to the increased use of many other metals. Some of these uses are based on chemical action. Metals vary in their physical properties, such as density and tensile strength. By a combination of metals, physical properties desired may be secured.

Can You Answer these Questions?

1. How does a dry cell produce an electric current?

2. What is the chief difference between a dry cell and a storage cell?

3. What are some of the properties of zinc which make it valuable commercially?

4. What is the explanation of the chemical process which takes place when a storage battery is charged?

5. What chemical changes take place in electroplating?

6. What are some important uses of copper?

7. What are some important uses of tin?

8. Why has aluminum become one of the really important metals in modern industry?

9. Why did the development of aluminum depend upon the coming of the Power Age?

10. What is meant by the density of metals? by their tensile strength?

11. Why are alloys important in modern industry?

12. What is galvanized iron?

13. While a storage battery is discharging, what is the chemical change on the lead plate? on the plate of lead peroxide?

14. Why is zinc paint more satisfactory than lead paint for interior decorating?

Questions for Discussion

1. What do you think we shall do for dry cells when our deposits of zinc have been exhausted?

2. How can you find out the density of metals other than those mentioned in the text?

3. Should you say that gold is an essential metal in our modern civilization? Why? Is it as important as lead?

4. Why is weight an important factor in the construction of airplanes and dirigibles?

5. What would probably be done in the canning industry if our tin supply were suddenly cut off?

Here are Some Things You May Want to Do

1. Gold and silver are called the precious metals. Try to find out why such a great value has been placed upon them and why they form man's standard of value for his systems of money.

2. Make a special list of the more common uses of certain metals. At the top of the chart list the metals, such as copper, zinc, lead, and so on. Under each metal list as many uses as you can think of.

3. Find out how zinc is used in the manufacture of rubber and in the manufacture of brass.

4. Make a spoon of Wood's metal. After you have made it, try to determine accurately the temperature at which it melts.

5. In this chapter we have not described all the metals with which you may be familiar. What do you know about mercury, for example? After experimenting see if you can add to this chapter a short description of the common properties of mercury. You might wish to write about some other metals.

6. Determine the density of lead, iron, zinc, gold (use a gold ring). You may recall the method from earlier work in science.

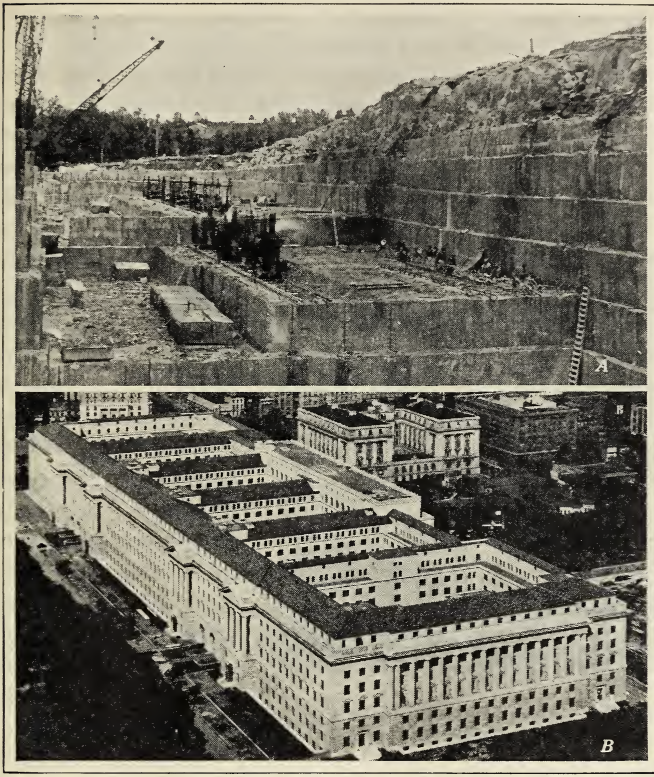
Chapter XIV · What Materials Other than Metals are used in this Age of Iron and Power?

Albert Brabazon

FIG. 148. The Construction of Large Cities such as this demands the Use of Materials Other than Metals

If you have ever visited a large city and have stood at the top of some tall building, you have probably marveled at the scene below, a scene such as that shown in Fig. 148. Here is visible evidence of the Age of Iron and Power. But if you will think about the processes which have made possible structures such as those you see, you soon realize that materials other than iron and steel have been used. First to come to your mind, perhaps, is stone. Granite and marble are both beautiful and enduring. Then you may think of glass, brick, plaster, and cement. These are made of sand, clay, limestone, and a few other substances that are found abundantly in the crust of the earth.

The Iron Age demands materials other than metals



Indiana Limestone Corporation

Fig. 149. Limestone is an Important Natural Building Stone

A, the quarry from which the stone is cut; *B*, a group of buildings in Washington, D. C., made from the stone

A. What is Building Stone?

Most of the stone used for building is marble, granite, sandstone, or limestone. All of these are abundant. Whole mountains are composed of them. Conditions under which the different rocks were formed, however, have made some much more valuable than others. Indiana limestone is

one of the most used of natural building stones. It is taken from huge quarries, as shown in Fig. 149. It is softer than marble and so is easily cut and shaped. The polished stone presents a beautiful whiteness. Many handsome structures similar to those in Fig. 149 are made of it. Examine some of this stone carefully with a hand lens or with the low power of a microscope and you may see (as in Fig. 150) that it is a mass of shells of tiny animals.

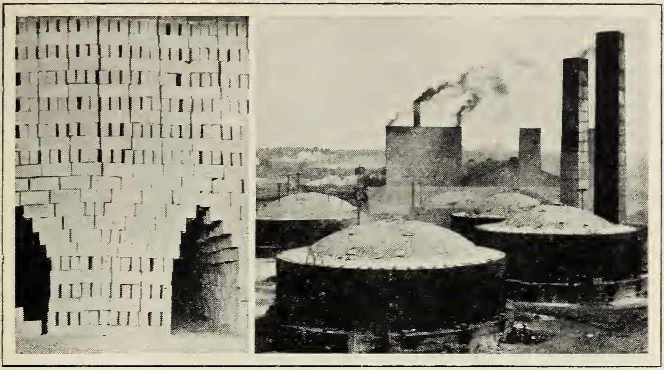
Fig. 150. Indiana Limestone (Magnified) is a Mass of Shells of Tiny Animals[1]

The finest marble and some of the finest granites come from Vermont. Marble is limestone changed by tremendous pressure. Granite is igneous. Marble is more easily cut and worked; granite is more durable. Both will take a fine polish, and the polished surface is more durable than a roughened one.

Brick and concrete are artificial stones

Artificial stones in the form of brick and concrete blocks are also used in building. Concrete we shall study a little later. Brickmaking (Fig. 151) goes back to extremely early times. Excavations in the ancient city of Ur show brick construction probably 6000 years old. In the simplest method of brickmaking, bricks are cut or molded from wet clay and dried in the sun. Long before the Christian Era, however, men had learned to harden bricks by burning them in kilns.

[1] Reprinted by permission from *Textbook of Geology*, Part II, by Schuchert and Dunbar, published by John Wiley and Sons, Inc.



Acme Ewing Galloway

FIG. 151. Brick is an Important Building Material

After being cut from soft wet clay the bricks are piled in kilns. The kilns are closed, and heat is applied. The bricks dry and harden

B. What is Glass?

Glass is made from silica (SiO_2) in the form of fine sand, sodium carbonate (Na_2CO_3), calcium carbonate in the form of limestone ($CaCO_3$), and a few other substances. Nearly pure products must be used for the manufacture of clear glass. There are many natural deposits of sand that are nearly pure silica, and there are many deposits of limestone that are nearly pure calcium carbonate. Sodium carbonate is a manufactured product. If we could follow the changes that take place in these substances as they are fed into a large furnace at a modern glass-making plant, we should see the mixture change to liquid. Sodium carbonate and calcium carbonate melt at about 850° C. Silica dissolves in the hot liquid somewhat as salt dissolves in water. The liquid is heated to a temperature of about 1260° C. Chemical changes take place in which carbon dioxide is released as gas. The liquid which remains may be as clear as pure water. As it cools, the liquid stiffens, becoming thick and

The process of glass-making is a chemical process

soft like taffy. It is not allowed to cool completely until it has been shaped into some form of glassware.

It is while glass is still soft that it is made into glass objects. It then may be shaped as desired. The shaping is done by blowing and by pressing in molds.

You may learn for yourself how glass objects are made. Get a piece of glass tubing about a foot long. The ends of the tubing will have sharp edges. You may "polish" these sharp edges with fire. Hold one end of the tubing in a gas flame until the glass is barely red. After the glass has cooled, run your finger over the edge and you will see that the sharpness is gone.

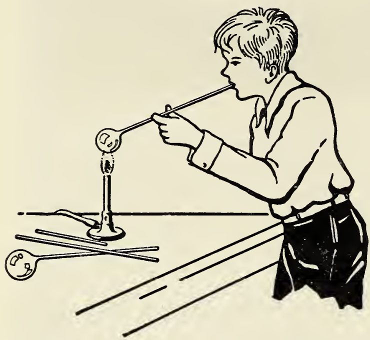
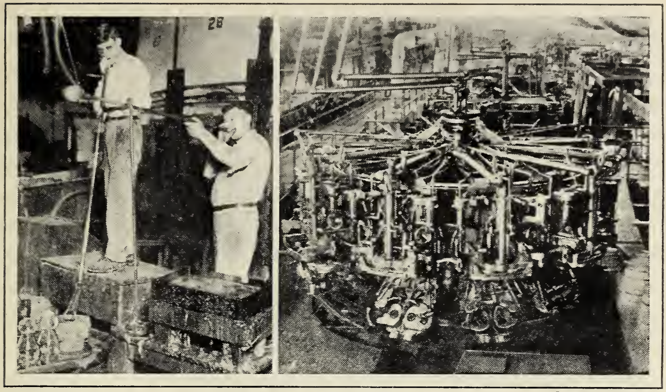


Fig. 152. If you have a Bunsen Burner and Some Glass Tubing in your Laboratory, you may easily learn how Glass Objects are Made

Then hold the other end of the tubing in the flame, slowly turning it, until the glass melts and the end of the tube closes. Now place the cool end of the tube in your mouth and blow. Can you blow a glass bubble (similar to a soap bubble) on the closed end of the tube, as shown in Fig. 152? This simple experiment will show you that glass may be shaped. A good deal of skill is required, however, to shape the hot glass as desired, for glass-blowing is a skilled trade.

Not many years ago glass-blowing was done by hand, or rather by lungs. Glass-blowers worked with long metal pipes. Look at Fig. 152. The glass-blower dipped one end of the pipe into the molten glass and pulled out a large drop just the right size. Then he blew a "bubble" of glass on the end of the rod, just as you did on the end of your tubing. And then he shaped it. More often than not he



Ewing Galloway

FIG. 153. The Processes of Glass-Blowing have changed as the Result of the Machine Age

Not many years ago glass bottles were made by hand. Today a machine does the same work very much more quickly

made bottles. The process was simple. He blew his drop of molten glass into a mold shaped like a bottle.

Now nearly all glass-blowing is done by machine, with compressed air. The process is enormously faster. In 1899, before machines were in use, 28,000 workmen in the bottle industry in the United States produced about one billion bottles. This is at the rate of about 100 bottles per workman per day. In 1925, 22,000 workmen with machines produced nearly four billion bottles. This is at the rate of more than 500 bottles per man per day. A single machine similar to that in Fig. 153 may make 50,000 bottles in a day. It should be said in passing that the glass-blowers' trade was a dangerous one. Men who followed this trade seemed especially susceptible to tuberculosis, and the average length of life among them was short. In this industry, as in many others, machines have taken the place of men in the more dangerous operations.

Glass-making has changed from a hand process to a machine process

After glass has been blown or otherwise shaped into desired forms, it must be annealed. What does that mean? If you were to take a glass bottle directly from the blowing machine into a room of normal temperature, you would find that it would almost surely crack; for glass must be cooled slowly. As soon as bottles are blown, they are placed on a conveyer belt in what is called an annealing chamber. The temperature at one end of the chamber is about 600° C. The bottles are carried along slowly, cooling as they are moved. A period of about two weeks is used to cool heavy bottles. Thinner glass, like light bulbs, may be cooled in twenty-four hours. This process is called annealing.

If we could observe the process used in making ordinary window glass, we might be surprised at the method used. Glass for windows is first blown into great cylinders, 30 or 40 feet in length but not more than 3 feet in diameter. When the glass hardens, the cylinders are mounted on tables. Notice how the rounded ends of the cylinders are broken off. After the glass is cool, a hot iron point is drawn quickly around the glass. The heat from the iron causes the glass to break. In a similar manner the long cylinders are cut into shorter ones. Then the shorter cylinders are cracked lengthwise. Each cracked cylinder is placed in a furnace that is hot enough to soften the glass. As the glass softens, the cylinder opens and the glass spreads flat on the surface of a table. The cylinder has become a sheet. Some of these processes are shown in Fig. 154. After the sheet of glass has cooled, it may be cut into sizes suitable for window glass. This process makes the cheapest kind of glass. Cheap glass has areas through which objects appear out of shape. Do you find such areas in the window glass of your schoolroom?

There is another process for making window glass. While the glass is hot and soft it may be run between steel rollers and "ironed out" into flat sheets. The rollers press the glass much as a clothes-wringer presses clothes.

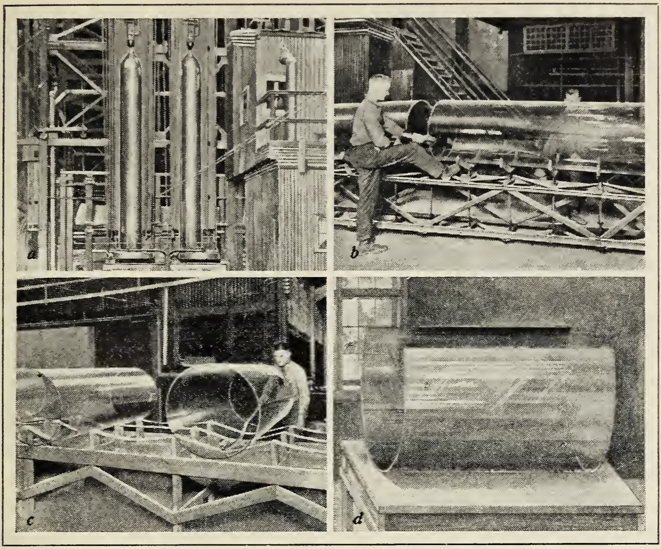


Fig. 154. The Making of Window Glass today is a Machine Process

a, compressed air is used to blow the molten glass into long cylinders; *b*, the long cylinders are cut into shorter ones; *c*, the short cylinders are cracked lengthwise by drawing a hot iron point along the cool glass; *d*, when the split cylinder is placed in a furnace, the heat opens it up and the glass forms a flat sheet

Different types of glass are made in different ways

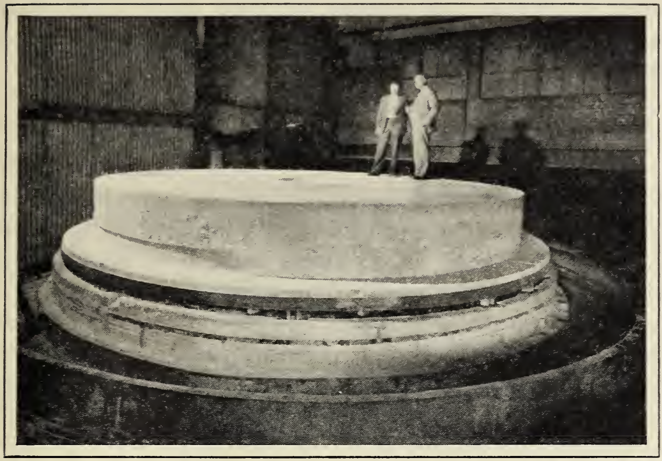
Plate glass is made with more care than ordinary window glass and is therefore more expensive. The liquid glass is poured out on a flat surface and pressed, as it cools, into a slab of nearly uniform thickness. Any irregularities are removed by grinding. The finished slab is so nearly uniform in thickness that it does not change the appearance of objects seen through it. You are aware of the difference between plate glass and window glass when you compare the glass in show windows of fine stores with the glass in windows of ordinary residences.

Glass used for cut-glass dishes is not the same in compo-

sition as window glass. Instead of lime, lead oxide, a combination of lead and oxygen, is used. Lead glass has a more brilliant sparkle than calcium glass, and it is less fragile. The finest cut glass is expensive because of the great amount of hard work that has been done on it. The melted glass is pressed into a mold of the shape that is desired. It comes from the mold as a smooth glass dish. The designs are then cut into the glass by grinding and polishing. For the cheaper cut glass the pattern is in the mold. When the dish comes from the mold, it therefore has the pattern impressed in it, and the process of cutting is reduced to merely grinding the edges and polishing the surfaces.

A striking example of great achievement in glass-making is the pouring of glass for the mirror of the 200-inch reflecting telescope to be built in California. This mirror is made of a glass that expands and contracts so little during changes in temperature that the likelihood of its breaking is small. About 100 tons of glass were melted in one enormous furnace. From this the molten glass was dipped and poured into a mold. The cooling of this enormous mirror was very carefully controlled. The entire process took about ten months. The finished piece, as shown in Fig. 155, weighs about 20 tons.

Fused quartz may be used for glass. It differs from glass in that it is transparent to ultra-violet as well as to visible light. Ultra-violet rays do not pass through ordinary glass. These rays are important for health, and for this reason quartz glass is sometimes used in the "sun rooms" of sanitariums. Sun's rays through quartz produce nearly the same healthful effect on the body as direct sunlight. Fused quartz expands and contracts with change in temperature so little that it may be heated red-hot and plunged into cold water without danger of breaking. It is clearer than glass and less fragile. It would serve as an excellent substitute for glass if there were enough of it. It is fine for



Ayres A. Stevens

Fig. 155. Special Glass is used for Special Purposes

Some day this piece of glass or another one like it will form a mirror for the new 200-inch reflecting telescope

dishes as well as for windowpanes, but by present manufacturing methods it is too expensive for general use.

Why is fused quartz so expensive? Since it is made from fine sand, certainly there is plenty of raw material. The cost is in the manufacturing process. It must be worked at a high temperature, and there are other practical difficulties. Much energy is required in the manufacture of fused quartz. As energy becomes more easily obtainable, we may use fused quartz more and more as a substitute for glass.

C. What are Mortar and Cement?

Mortar is made from slaked lime and sand. Slaked lime is made by mixing lime with water. Some experiments will show how mortar is made and how it is used. The manufacturing process begins with limestone. This, as you know, is calcium carbonate ($CaCO_3$). When heated it decom-

poses, or breaks up, forming calcium oxide (CaO) and carbon dioxide. The bricklayer calls this quicklime. A simple expression shows the chemical change:

$$CaCO_3 \longrightarrow CaO + CO_2$$

Get a sample of quicklime from a bricklayer or plasterer. Place a small amount (say 50 grams) in a glass and add, slowly at first, enough water to cover the lime. You immediately see evidence of chemical action. Heat is produced, and the appearance of the lime changes. After chemical action has ceased, you have in the glass white pasty slaked lime. Its chemical name is calcium hydroxide ($Ca(OH)_2$).

You may have seen workmen slaking lime. The chemical change is:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Mortar hardens because of chemical action

Mortar is made by mixing this pasty slaked lime with sand. It seems to be just the proper thing for use in laying brick. Bricks of a brick wall are cemented together with it. The bricks are laid in the mortar while it is soft. After it has been exposed to air, the mortar dries and hardens. Mortar is also used as plaster for the walls of houses. After it hardens, whitewash or stucco may be spread over it.

The slaked lime exposed to air is slowly changed by chemical action with carbon dioxide, forming calcium carbonate:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

This chemical change is known as "setting." Sand is used in mortar to keep the lime from becoming absolutely solid, and so that molecules of carbon dioxide may penetrate to the interior. Chemical action within the mortar may continue for years and possibly for centuries as calcium hydroxide slowly changes to calcium carbonate.

As you have followed this explanation, have you noticed that, in this succession of chemical changes, atoms of cal-

cium run through a complete cycle, or round, returning to their original state? Calcium carbonate ($CaCO_3$) forms from calcium hydroxide ($Ca(OH)_2$) as the mortar sets. Calcium hydroxide forms from calcium oxide (CaO) as the lime is slaked. Calcium oxide is formed by heating calcium carbonate.

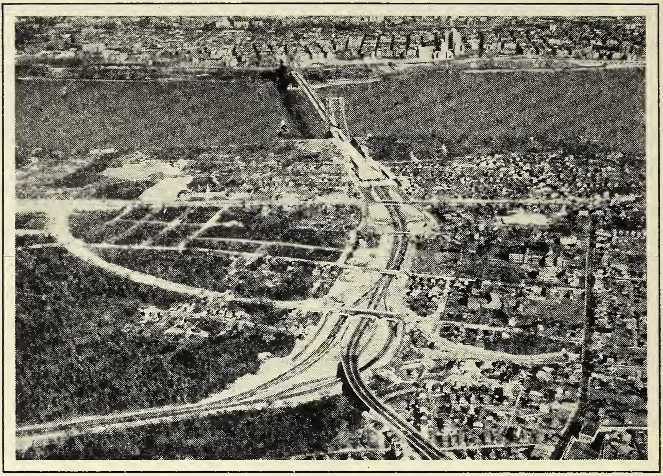
Cement is in some respects similar to mortar. It is made by heating a mixture of limestone and clay. The chemical changes in this process are more complex than in the making of quicklime. The materials from which cement is made are dried and powdered, mixed in proper proportions, and placed in a furnace. The mixture is heated until it just begins to melt and run together. As it is heated, water and carbon dioxide are driven out of it.

Cement is used more widely than mortar in construction work because it can be used under water

A most important difference between cement and mortar is that cement will harden (or set) under water; mortar will not. The chemical change in setting cement is in fact due to action with water. Air has no necessary part in it. Enormous quantities of cement are used, therefore, for building under water. The chemical changes in setting go on slowly and may be continuous for some years. The strength of the structure increases during all the time the cement is setting.

One of the main uses for cement is in building concrete highways. Concrete is a mixture of cement with sand and stone. During the years since the automobile has come into common use, thousands of miles of concrete highways have been built. Look at Fig. 156.

Other important uses of cement are for building tunnels and dams. One great dam is at Muscle Shoals in the Tennessee River (shown in Fig. 157). It is a concrete structure 4300 feet long and 142 feet high. The water falling over this dam is a source of power. The total water power from all sources in the United States in 1932 was about 15,000,000 horsepower and from Canada a little



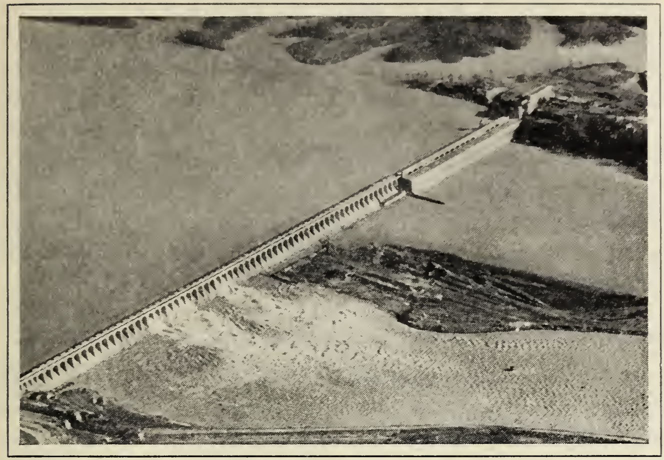
Fairchild Aërial Surveys, Inc.

Fig. 156. With the Coming of Concrete, Vast Networks of Concrete Automobile Highways lead from All our Large Cities

more than 6,000,000 horsepower. This one concrete structure may, when completed, produce 3,000,000 horsepower.

Construction work on the greatest of all dams is now in progress. It is in the Boulder Canyon of the Colorado River. When completed it will be 730 feet high. Some 4,500,000 cubic yards of concrete (about 10,000,000 tons) will be used in its construction. The dam will hold back a vast reservoir, or storage basin, of water, sufficient to cover 30,000,000 acres of land to a depth of 1 foot. This is an area almost equal to that of the state of New York. Water from the reservoir will be used to irrigate the desert lands of neighboring regions and to generate electricity. There will be sufficient water to generate some 663,000 horsepower. By way of comparison, the same amount of power released through electric locomotives would be sufficient to keep two hundred heavy trains continually mov-

Cement plays an important part in the building processes of the Iron Age



Acme

FIG. 157. Great Quantities of Concrete are used in Building Dams such as this One at Muscle Shoals

ing. This huge dam, then, will mark another stride forward in the effort to use natural forces to do the work of the world.

The future will without doubt see the extension of many similar pieces of construction. Certainly sometime there will be great developments along the Mississippi River. At Minneapolis the river is some 800 feet above sea level. In time of flood it flows as a raging torrent, overflowing its banks and spreading ruin far and wide. As man seeks to control his environment what will he do with this great river? Engineers can furnish the answer. They could build a number of dams along the course of the river, like the ones now at St. Paul, Minnesota, and at Keokuk, Iowa. These would hold back the floods from the heavy rains, and thus thousands of acres of farm lands could be preserved from damage. Besides, each dam would be a source of water power, to be converted into electrical energy. All this would add enormously to the wealth of this great valley.

What would it cost to carry out such a work along the Mississippi? Probably we should ask what it costs not to do it. Most of the construction work would be with iron and cement. We have plenty of both. Iron ore is of no use so long as it remains in the ground; neither is limestone or clay. Labor would be required, but there is no lack of men and machines for that. Our great ambition should be to free ourselves from the fear of hunger and ruin, by extending the power to use our abundant natural resources for the common good.

Many materials other than iron and steel are used at the present time. Most important of these are the building stones and other substances, such as cement, which make modern construction work possible. All these are products of the environment. As man increases in his ability to use them, civilization will surely change.

Can You Answer these Questions?

1. How does marble differ from limestone in origin and properties?

2. What are some of the chemical changes that take place in glass-making?

3. How does fused quartz differ in composition from glass? In what ways is fused quartz superior to glass for windows?

4. What chemical changes take place in the making of quicklime? in the processes by which mortar hardens or sets?

5. What are the chief differences between mortar and cement?

6. What is concrete, and why is it so widely used today?

7. How does window glass differ from plate glass? How does cut glass differ from bottle glass?

8. Why is the annealing process necessary in glass-making?

9. Which is better for construction work under water: mortar or cement? Why?

Questions for Discussion

1. What relationships do you think there are between the use of iron and the use of cement? Consider such an industry as the building industry.

2. Why do you think ancient peoples, such as the Greeks, used marble more than other stones for building purposes?

3. Is kiln-dried brick better than sun-dried brick for building purposes? Why do you think so?

4. Why was the old trade of glass-blowing dangerous to health?

5. When blowing machines were introduced into bottle-making, some of the glass-blowers lost their jobs. Should the machines have been introduced?

6. Do you think it likely that fused quartz will in the future entirely replace ordinary glass?

7. Do you think that man will ever make full use of the energy of falling water? What changes do you think will help to bring this about? What changes do you think it will make in living?

Here are Some Things You May Want to Do

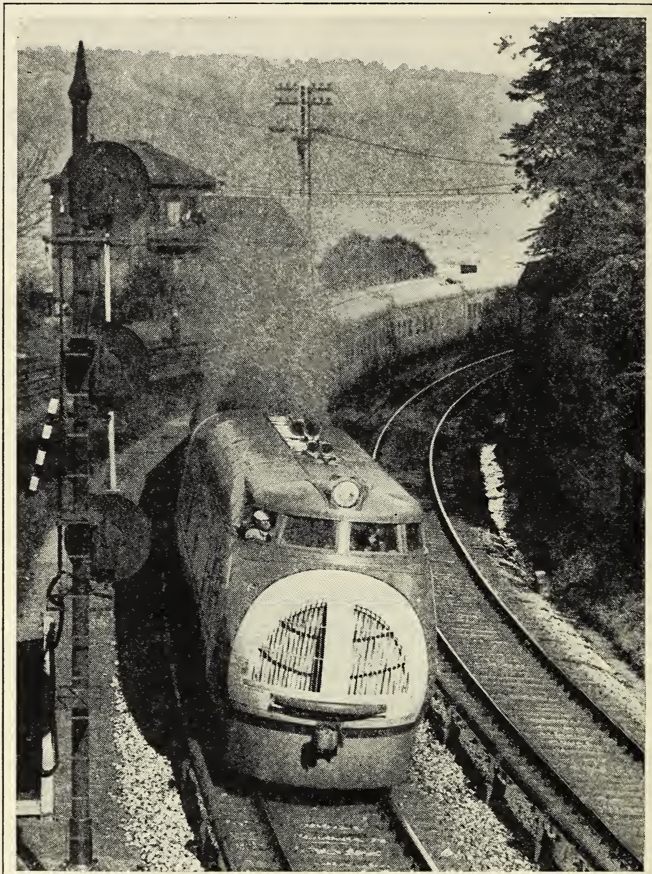
1. Make a study of changes that have taken place in the building industry as the result of new materials. Could the modern skyscraper have been built one hundred years ago?

2. A special glass called pyrex is used for cooking utensils. See what you can find out about this glass, how it is made, and why it stands up under heat.

3. Write to your local congressman or representative, and ask him for information concerning some of the great power projects the government has under way.

4. You can find out about some of the properties of glass for yourself. Try to bend some glass tubing, blow glass bubbles as described in the text, or make a glass pen which will write.

5. Place some marble chips in a bottle and add a few drops of hydrochloric acid. Hold a burning candle over the mouth of the bottle. Explain your observations.



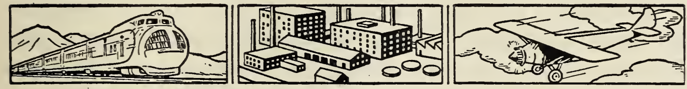
Wide World

Fig. 158. Through a Constantly Increasing Ability to use the Materials and Energy Resources in his Environment, Man is changing Many of his Ways of Living

What developments made the streamline trains possible?

UNIT IV

How has Man gained Control over the Energy Resources of the Earth?



Chapter XV · What are Some of the Relations between Force and Motion?

Chapter XVI · What are Some of the Relations between Force, Work, and Power?

Chapter XVII · What are Some of the Characteristics of Energy?

Chapter XVIII · How does an Engine change the Potential Energy of Fuel into Kinetic Energy?

Chapter XIX · How does an Airplane use Energy?

IN YOUR previous work in science you have learned of the forces that are changing the surface of the earth. These are powerful forces, for, as you know, they wear down mountains and work continuous changes on the surface of the earth. These forces have their origin in solar energy, and their effects are seen in the flow of air and water over the earth and in the chemical changes that go on in living cells.

In this unit you may learn how man has gained a measure of control of energy and how he has used this control to run machinery. Energy of coal, with its origin in green plants, is used to pull heavy trains. Energy from falling water is used to light our homes and streets. In this Age of Power you see on every hand, machinery in which energy from natural resources is used to do the work of the world.

In this unit you may learn something of the relations of forces and energy and something of the manner in which man has harnessed these forces of nature and used them to serve his purposes. It tells, in brief and simple language, the story of man's progress from the time when physical work was done by the muscles of men and by beasts of burden, to the time when energy from natural resources is released through machines and used to do the work of the world. This unit is, in fact, an account of one of man's greatest achievements.

Chapter XV · What are Some of the Relations between Force and Motion?

In Fig. 159 the artist has pictured some familiar kinds of forces upon the earth. As you probably know, forces are in evidence all about us. Their effects may be seen in running water, in wind, in hot steam, and in the activities of living things. Water flowing in streams exerts force as the swiftly flowing stream moves the rocks that lie in its bed. Plunging over a cliff, the stream strikes with powerful force on the rocks below. A strong wind may break down trees, destroy buildings, and carry enormous quantities of earth in the form of dust from one region to another. The force of the moving molecules of hot steam drives machinery. Forces from the muscular action of living things enable living things to move about. Observe the football team advancing the ball. In all these observations you may see some examples of powerful forces.

Forces are in evidence all about us

In addition to the forces mentioned there is the force of attraction between the earth and objects on it and between the earth and the heavenly bodies. This is the force of gravity. The attraction between the earth and objects on its surface pulls objects toward the center. You become aware of the force of gravity as you try to raise an object away from the surface of the earth. The force of attraction between the earth and a large rock may be so great that you alone cannot move the rock.

A force is required to raise an object because the force of gravity tends to hold the object down. Force is also required to keep an object moving, because friction with air or with the earth on which the object is moving tends to make it stop. In doing the work of the world we must distribute food, clothing, machinery, and other things. We

Control of natural forces reduces human labor

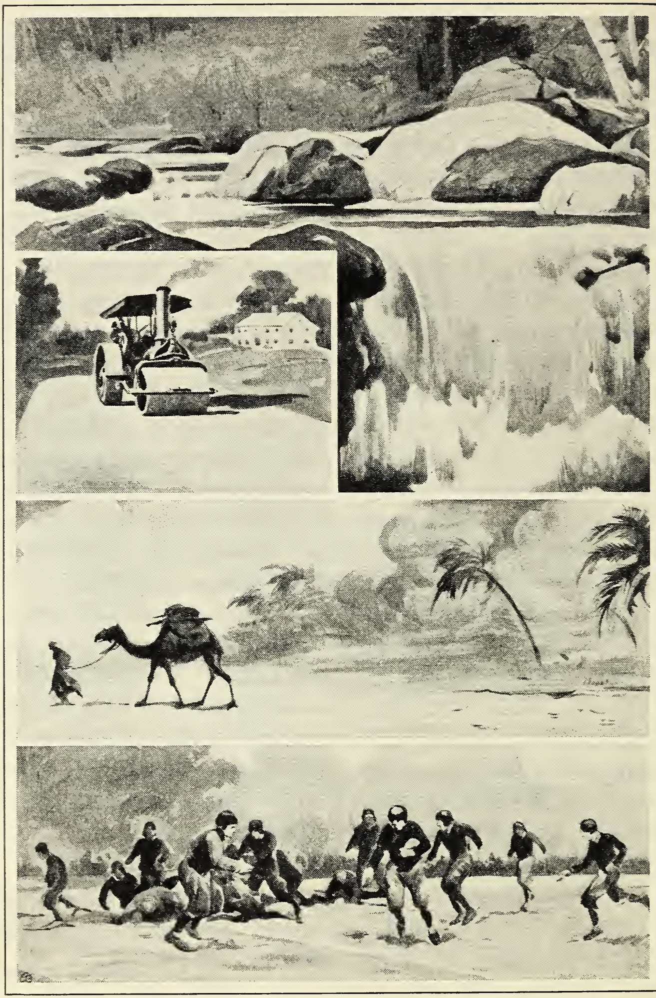


FIG. 159. Forces are in Evidence all about Us

must construct dams, bridges, and buildings. In all this work forces must be applied.

In the earlier periods of human history the work of the world was done by men and by beasts of burden. Galley slaves drove ancient vessels (Fig. 160) through the water, horses pulled heavy stagecoaches, camels carried burdens over the desert, and within workshops and in fields heavy work was done by human labor.

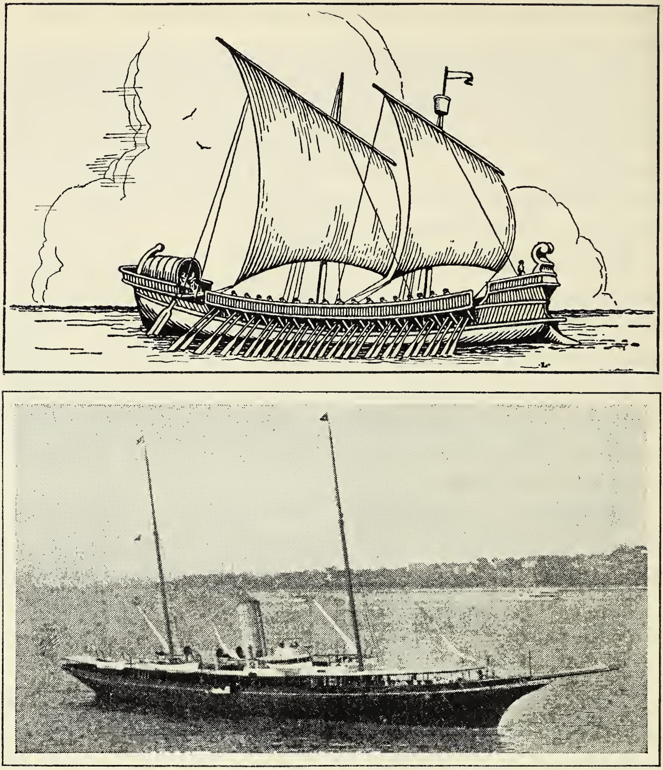
With the nineteenth and twentieth centuries, however, there has come the Age of Power. Men have learned how, with the aid of machinery, to use natural forces to do the work previously done by men and by beasts of burden. Men have in part been freed from toil as a result of this control. Vessels and vehicles are now driven by steam, gasoline, and electricity; the heavy work in factories is done by machinery.

Let us study these forces with some care. You have a general knowledge of what a force is, but in the study of man's control of energy you will need exact knowledge.

A. What is a Force?

Force and motion are closely related

An automobile on a cement floor may be moved by the force of a man pushing against it. If the force continues, the car will move faster. A force in the direction opposite to the direction in which the automobile is moving will cause it to move more slowly. If the opposing force is great enough, the moving car will be stopped. Similarly a train is set in motion by the force of steam from the boiler of the locomotive. The train moves faster as the force continues. Brakes are applied to stop the train. In this case the force of compressed air pushes the brakes against the wheels, and the train moves more slowly and comes to a stop. Thus you see that a force may start an object in motion, and it may make a moving object move faster. You also see that an opposing



Keystone

Fig. 160. With the Coming of the Age of Power have come Great Changes in Man's Ways of Working

Contrast the galley (above), driven by power of human muscles, and the modern yacht (below)

force may stop a moving object or at least may cause such an object to move more slowly. From the above you may define force by saying that it is a push or a pull.

What is centrifugal force? A moving object tends to move in a straight line. Thus an object tied to a string may be moving in a circle, but it seems to pull away from the center. If the string should break, the object would

move in a straight line from the point where it was released. The force thus displayed is centrifugal force. Fig. 161 shows an effect of centrifugal force. The outward pull of the hammer increases as the man swings round and round. When the hammer is released, it travels in a straight line away from the circle.

Common observations will help to show clearly the effect of this force. Occasionally an automobile traveling at high speed comes suddenly upon a turn in the road. The driver turns the steering wheel to go around the turn, but the tendency to continue in a straight line is so strong that the car skids and sometimes leaves the road (Fig. 162). In the air a pilot banks his airplane, as shown in Fig. 162, in order to turn it from its straight course. A sudden change in the direction of a rapidly moving airplane, as in racing, may cause great discomfort to the pilot. A plane may travel as fast as 300 miles an hour. Inside the body of the pilot the blood is being driven along by the force of the heartbeat. As the plane turns at this high speed, the blood in the aviator's body, tending to move forward in the same straight line, is forced to the side of his body. Thus the sudden turn interferes with the movement of the blood through the pilot's body. Aviators sometimes lose consciousness while making a sharp turn at high speed. After the plane has straightened out in its course, the blood in the body of the aviator moves normally again, and consciousness returns.

An object in motion tends to move in a straight line

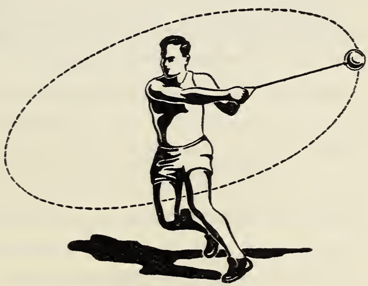
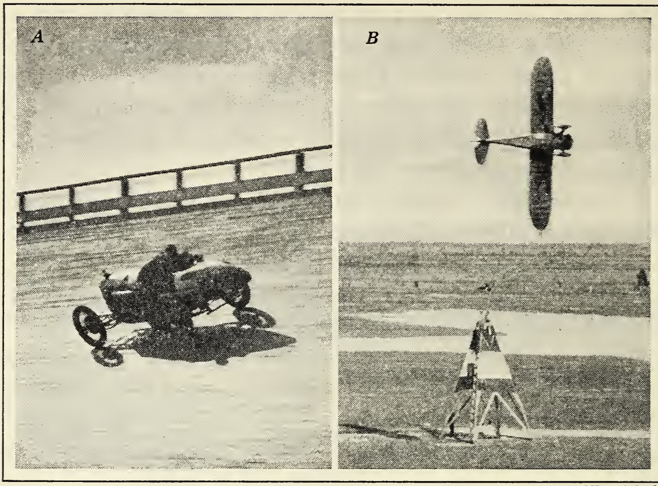


Fig. 161. Owing to Centrifugal Force, the Outward Pull of the Hammer increases as the Man swings Around and Around

From such observations we may summarize the rela-



Pictorial News Co. Wide World

Fig. 162. Centrifugal Force plays an Important Part in the Events of Everyday Life

Why is the race track in *A* banked on the turns? What happens to the pilot in the racing plane, *B*, as he turns a corner at high speed?

tions between forces and objects. First, an object at rest remains at rest until a force causes it to move. Second, an object in motion will continue in motion without change in speed unless a force acts upon it to make it go faster or slower. Third, an object in motion will continue in motion in a straight line unless some force acts upon it and causes the direction to change.

An object in motion tends to continue to move

Let us develop these relations a little more fully. The first is obvious. An object does not start to move unless something starts it. The second is less obvious. The common observation is that force must be continually applied to keep an object moving. A ball hurled upward into the air rises with lessening speed until it finally comes to rest and starts downward. An automobile does not run on and on after the power is shut off. It finally comes to rest. There is a force

(gravity) that opposes the upward motion of the ball and tends to pull it toward the earth. There is a force (friction) between the moving parts that opposes the motion of the automobile. But if there were no force of gravity and no friction, the moving ball or the moving automobile would continue to move in a straight line with undiminished speed.

The relation of force to change in the direction in which an object is moving (the third relation mentioned) may also not seem obvious. In common experience about the only condition in which an object moves in a straight line is when it is falling directly toward the center of the earth. A baseball struck with a bat moves along a curved line, and in a little while it falls to the ground. You may think a rifle bullet moves in a straight line, but it does not. A bullet moves very rapidly, to be sure, and the line along which it moves may be so slightly curved that it seems straight. A marksman knows, however, that if he is shooting at a distant target, he must aim a little above the target in order to hit it.

Gravity pulls objects toward the earth

Let us illustrate this. A baseball may be struck with force enough to drive it 250 feet in one second. A rifle bullet may travel 2500 feet in one second. Suppose a gun were fired from a position such as is shown in Fig. 163. The gun barrel is held just parallel to the surface of the earth. Careful observation will show that at the end of one second the bullet from the gun will have curved downward by about 16 feet. If the baseball were hit from the same position and started along a line that is just parallel to the surface of the earth, the line along which the ball travels will also have curved downward at the end of one second by about 16 feet. The rifle bullet curves downward 16 feet while traveling 2500 feet, and the baseball curves downward 16 feet while traveling 250 feet. Both are 16 feet nearer the surface of the earth at the end of one second. Evidently a force is acting on the moving bullet and on

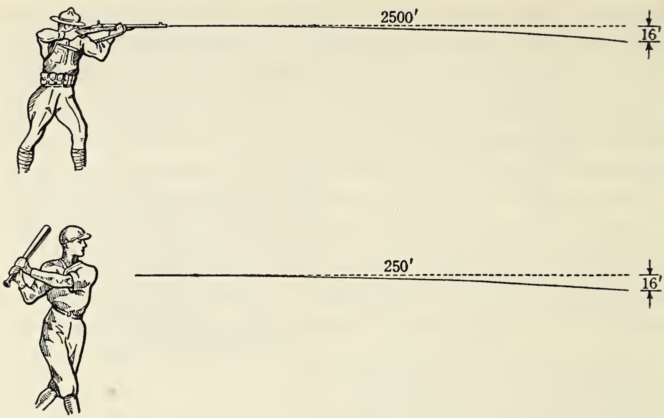


Fig. 163. The Force of Gravity acts upon Objects in Motion and changes the Direction in which they Move

Read your text again for an explanation of this diagram

the moving ball, and this force changes the direction of the motion. This force of attraction in both cases is that of gravity. It acts upon the objects in motion through the air and changes the direction through which they move. But if there were no force of gravity, the ball and the bullet would continue in a straight line.

B. Is there a Gravitational Attraction between All Objects?

The effect of the force of gravity plays an important part in everything you do in your daily life. Consider the things you do most often during the day: walking, running, playing ball, jumping. Would any of these things be possible without the help of gravity?

The effects of this force are familiar to us, but the force itself is one of the most puzzling of natural phenomena, or happenings. Sir Isaac Newton first stated the laws of gravitation. Yet neither Newton nor anyone since his time

has explained satisfactorily why objects are attracted to the earth by the force of gravity. Even though this force cannot be explained, many things may be learned about it.

When you have read about the solar system, you have learned that, acting through distant space, gravitation holds the moon in its course around the earth, and the planets in their courses around the sun. You have learned in your study of the heavenly bodies that centrifugal forces set up by the revolution of these bodies are in the opposite direction to the forces of attraction between them. These bodies continue in their regular courses only because the attractive forces and the centrifugal forces are balanced one against the other.

In the case of the moon, for example, the centrifugal force which tends to pull the moon away from the earth is just equal to the force of attraction which tends to pull these two bodies together. These equal forces may be measured, and they are in the order of twenty billion billion tons. You see some of the effects of this great force as you watch the tides of the ocean rise and fall.

Every particle of matter attracts every other particle

The attractive forces within the solar system are extremely complex, for there is an attractive force between the sun and each of the planets and their moons, and there is an attractive force between each of these bodies and every other in the system. In addition there is a force of attraction between the stars and all the other bodies distributed through the universe.

The force of attraction of one object for another may be measured

The force of attraction of one object for another is universal. Between objects on the earth, such as the ones you may lift, it is so small that it cannot be observed by ordinary means. You cannot observe the attraction of one rock for another. The attraction of a ball of lead the size of a basketball for a ball of lead the size of a baseball, however, may be measured if very accurate instru-

ments are used. This force is extremely small when compared to the attraction of the earth for these objects, since the greater the masses of the objects the greater the force of attraction of one for the other. The force of attraction of the earth for a lead ball six inches in diameter is about forty-five pounds. The lead ball seems heavy, but in comparison with the mass of the earth the mass of the ball is extremely small.

C. What is the Weight of an Object?

With a simple spring balance similar to the one shown in Fig. 164 you may measure the earth's pull on an object. The spring is stretched when an object is hung from it. Why? Because the earth attracts the object. The earth pulls all objects toward its center. It is easy to measure the force of attraction between the earth and objects on the earth. When you say that a certain object weighs so many pounds, you really mean that the attractive force between the earth and the object is so many pounds.

Weight is a measure of the force of gravity

Pounds, ounces, and tons — all these are common units of weight. How are these units defined? For the "standard pound" an amount of metal sufficient to give a unit of weight of convenient size was chosen. When a standard-pound weight is hung from a spring, it causes the spring to stretch a certain amount. Any other object which causes the spring to stretch the same amount weighs the same. An object which causes the spring to stretch twice as much weighs twice as much. An object which is attracted with only one sixteenth of the force of one pound weighs an ounce. An object which is attracted by two thousand times as much force as the pound weighs one ton.

A pound of force is the force of attraction between the earth and a standard pound of matter. Is a pound a pound the world around? It should be if the force of gravity

were the same in all places. But the force of gravity is not quite the same everywhere. Why? The attractive force between an object and the earth changes as the distance changes between the object and the center of the earth. A little thought will show you that the distance of an object on the earth from the center of the earth may change. As it does, weight also changes. Thus at the top of a mountain about ten thousand feet high an object which weighs a ton at sea level will weigh about one pound less than a ton.

The weight of an object is not the same everywhere

If it were possible to move an object outward from the surface, that is, away from the center, the pull of gravity would become less. If it were moved toward the surface, that is, nearer the center, the force would become greater. This does not mean, however, that if you could dig a deep shaft far down toward the center of the earth, the weight of an object would become greater and greater as you went deeper and came close to the center. As a matter of fact, the object would weigh less and less. "How is this possible?" you may ask. Remember that the force of gravity is universal and that every particle of matter in the universe attracts every other particle. Thus at a depth of some four thousand miles the force of gravity pulling the object toward the center of the earth would be balanced by the pull of all the matter surrounding the object between the center and the surface. At the center of the earth the weight of an object is zero because the pull from all directions is the same. The weight would become less and

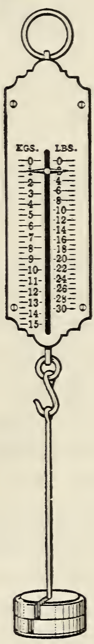


Fig. 164. A Spring Balance measures the Weight of an Object because the Force of Gravity attracts the Object

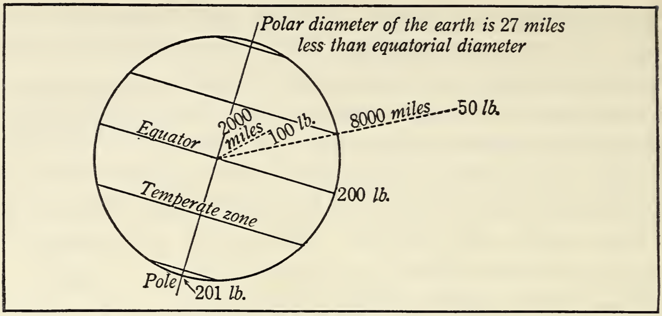


Fig. 165. As an Object is moved away from the Center of the Earth, the Pull of Gravity becomes Less

The diagram shows the weight of a standard pound at various points. Why should the weight become less as the object nears the center of the earth?

less as the object was lowered from the surface toward the center. Fig. 165 will make this clearer.

Again, the force of gravity is a little greater at the poles than at the equator. Why? Remember that the earth is nearly but not quite a perfect sphere. It is slightly flattened at the poles. Thus the force of gravity is a little greater at the poles, for there the distance to the center of the earth is less than it is at the equator.

A second reason why the force is greater at the poles is that the earth is turning on an axis. The centrifugal force is greatest at the position on the earth where the surface moves fastest. This is at the equator. This centrifugal force, however, is very small in comparison with the force of gravity. The difference in the force of gravity due to greater distance from the center is also small. If the pull of gravity on a stone is 200 pounds at the equator, the pull of gravity on the same stone would be about 201 pounds at the poles.

Does all this mean that the amount of matter in the standard pound changes when its position is changed? It does not, for it is only the force of the earth's pull on the

same amount of matter that is different. You must learn to distinguish between mass and weight. It is the mass of an object that remains the same wherever it may be. The weight of a definite mass of matter changes as it is moved from one place to another, because the earth's attraction for objects differs slightly in different parts of the world. The standard pound must be thought of as a pound mass.

The mass of an object is always the same

The metric system of weights and measures is commonly used in scientific work today. In this system the unit of mass is almost exactly 1 cubic centimeter of water at the temperature of its greatest density, 4° C. This mass is 1 gram. The kilogram (equal to 1000 grams) is the metric unit in common use.

The value of the pound is fixed by an act of Congress as $\frac{1}{2.2046}$ of a kilogram. This means that the kilogram is equal to about 2.2 pounds. One gram is therefore equal to about $\frac{1}{454}$ of 1 pound $(1000 \div 2.2 = 454)$. In Fig. 167 are shown two of the standard kilogram weights used by the government to check other weights.

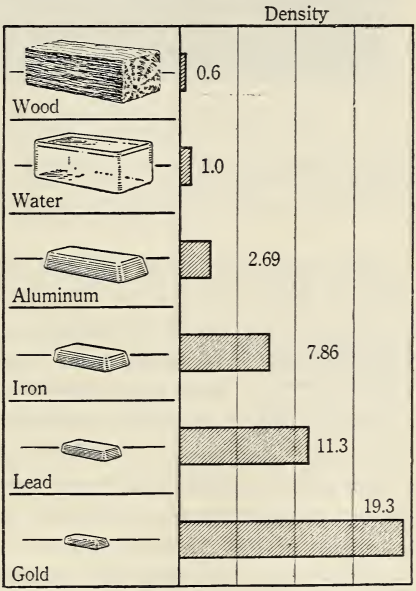


FIG. 166. The Largest Object does not always weigh the Most. The Weight per Unit Volume is the Density

At the left are shown various substances, and at the right their density. Each of the blocks shown would have the same weight. Why does their volume differ?

United States Bureau of Standards

FIG. 167. The Standard Kilogram is 2.2046 Pounds

The illustration shows two of the standard kilogram weights used by the government for checking purposes. These weights are kept under glass and great care is used in handling them. They are never touched by hands, and are lifted only with felt-covered forceps

The force of gravity is different on different planets

The pull of the moon and the pull of the planets on objects on their surfaces are not the same as the pull of the earth on objects on its surface. The force of gravity on the surface of any of the heavenly bodies depends on the mass of the body. The mass of the earth is more than eighty times the mass of the moon. The force of gravity on the surface of the earth is about six times the force of gravity on the moon. If the attraction between the earth and your body is a force of 120 pounds, that is, if you weigh 120 pounds, the attraction between the moon and your body if you were on the moon would be a force of but 20 pounds. The mass of your body would be the same of course on the earth as on the moon.

The mass of Mars is about one third the mass of the earth. Its surface gravity is only a little more than one third the surface gravity of the earth. Objects of equal mass will weigh three times as much on the earth as on Mars. The mass of Jupiter is more than three hundred times the mass of the earth. The surface gravity on Jupiter is two and six-tenths times the surface gravity on

the earth. The surface gravity on the sun is nearly twenty-eight times the surface gravity on the earth. A mass of 1 pound would weigh 28 pounds on the sun.

Our system of weights, then, is really one which measures the pull of the force of gravity on earth. Forces are measured in pounds or in grams.

Air pressure and water pressure may be measured in pounds (or grams) per square inch (or square centimeter). When you say you are pushing against an object with a force of 50 pounds, you mean that the force you are exerting is great enough to raise a mass of 50 pounds against the force of gravity. This same push of 50 pounds may be sufficient to move an automobile weighing 4000 pounds over a smooth floor. Do you see why?

D. How does the Force of Gravity affect Falling Bodies?

Objects fall with uniform acceleration

If a body is taken far above the earth and released, it will fall toward the center of the earth. The force of gravity pulls the falling object all the time, and the object falls faster and faster. The increase in velocity, or speed, is by equal amounts during successive intervals of time. The velocity is said to be uniformly accelerated. Acceleration is rate of gain or loss in velocity. Uniform acceleration is change in velocity by an equal amount in equal intervals of time.

In your study of falling objects you must recognize the effect of two forces. The force of gravity pulls an object down, and friction with the air tends to hold it back. We may study these forces one at a time.

Consider first the force of gravity. Suppose you think of a steel bullet dropped from a balloon and falling through ten thousand feet of air. Suppose there is no friction at all. The moment the bullet is released it starts to move toward the center of the earth. The velocity increases as it falls, for the force of gravity is a continuous pull. At the end of

two seconds the bullet is falling faster than at the end of one second. At the end of three seconds it is falling still faster. If there were no friction with the air, the gain in velocity during each second the bullet is falling would be the same. It would be uniformly accelerated.

From careful observation it has been learned that a falling body like the bullet would be falling at the end of one second, if there were no friction with air, with a velocity of about 32 feet per second. At the end of two seconds it would be falling at the speed of 64 feet per second, and at the end of three seconds the speed would be 96 feet per second. In other words, the velocity with which it would fall increases at the rate of 32 feet per second each second.

The higher the altitude the longer it takes an object to reach the ground. The longer this time is, the faster the object is falling and the greater the force with which it will hit the ground. If this bullet were dropped from such a height that it would take ten seconds to reach the ground, its final velocity would be 320 feet a second; if twenty seconds, its final velocity would be 640 feet a second, and so on.

Consider now another question. How far will a uniformly accelerated body, such as the bullet referred to above, fall in any given period of time? If it were not held back by friction with air, how far would it travel in one second? in ten seconds? in twenty seconds? Look at the accompanying table, which is diagramed in Fig. 168.

	Velocity of Fall (in Feet)	Distance of Fall (in Feet)
At the beginning	0	0
At the end of the first second	32	16
At the end of the second second	64	64
At the end of the third second	96	144
At the end of the fourth second	128	256
At the end of the fifth second	160	400
At the end of the sixth second	192	576
At the end of the seventh second	224	784
At the end of the eighth second	256	1024
At the end of the ninth second	288	1296
At the end of the tenth second	320	1600

Looking at the second column of the table, you will see the distance the object has fallen in any given period of time. What are the relations between this distance and the time?

Find the average velocity of the falling body for the given length of time. To find the average velocity, merely add the beginning velocity to the final velocity and divide by two. Then multiply the average velocity by the number of seconds during which the object is falling.

For example, at the end of five seconds the velocity of a falling body would be 160 feet a second (32×5). The average velocity for five seconds is therefore $\frac{0+160}{2} = 80$. Multiply 80 by 5 (the number of seconds), and you get 400, the number of feet the bullet fell in this time. Similarly you may find that the bullet will fall 1600 feet in ten seconds. If you continued the table to 25 seconds, you would find that at the end of this period the bullet would be falling with a velocity of 800 feet per second and would have fallen 10,000 feet.

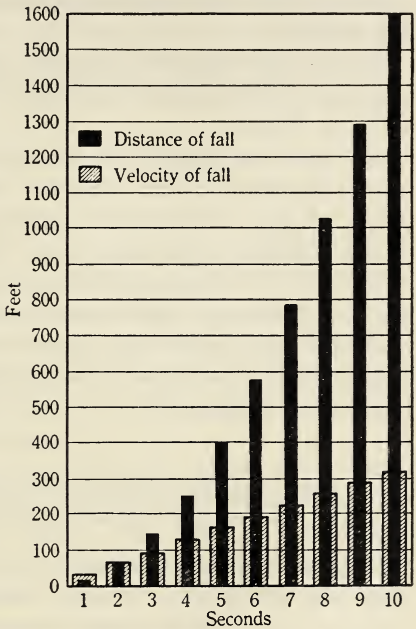


FIG. 168. Objects fall with Uniform Acceleration

By the use of this graph can you support the statement that the increase in velocity of a falling object is by equal amounts during successive intervals of time? How does this graph differ from one which would show the same facts for an object moving away from the earth?

In other words, a bullet dropped from a balloon 10,000 feet in the air, if there were no air resistance, or friction, would reach the ground in twenty-five seconds and at the moment it hit would be moving with a velocity of 800 feet per second.

From these figures you may come to the conclusion that the uniform pull of gravity uniformly accelerates the velocity of fall.

Objects of different masses fall with the same velocity

At one time people believed that objects of different masses would fall with different velocities. Back in the seventeenth century Galileo showed that this was not so. He dropped two metal balls of different weights from the leaning tower of Pisa and thus demonstrated to a passing crowd that the balls would fall with the same velocity. Previously people believed that heavier objects would fall faster than lighter ones.

E. How does the Force of Gravity affect an Object that is moving away from the Earth?

An object moving away from the earth loses speed at a uniform rate

A bullet leaves an ordinary rifle with a velocity of about 3200 feet per second. Let us imagine that the bullet is shot straight upward. If there were no friction with the air, the velocity of the bullet would diminish, as it rises, at the rate of 32 feet per second each second. The velocity of an object moving away from the earth diminishes at the same rate that the velocity of an object moving toward the earth increases. Therefore the bullet would continue to rise for one hundred seconds ($3200 \div 32 = 100$). The average velocity at which it travels upward would be 1600 feet per second, and in the interval of one hundred seconds it would rise 160,000 feet, or about 30 miles. At the end of this time its velocity would be zero, and it would start to fall. Of course there is friction

with the air, and so the bullet would not really rise nearly as high as 30 miles.

Thus you see that a bullet shot straight upward from a gun is acted upon by the same force that pulls a falling bullet to the earth. As the bullet moves away from the earth, the force of gravity diminishes its velocity uniformly. As it falls toward the earth, the force of gravity increases its speed uniformly.

If you live near some large harbor, you may have visited the forts there. Perhaps at some time you have been aboard large battleships. If so, you have probably seen the huge guns which hurl shells for many miles at an unseen target. Have you ever wondered how it is possible to calculate exactly the proper angle at which the gun should be placed or the amount of powder that should be used? While many things must be considered in solving these problems, one definite part of the figuring concerns itself with the effect of gravity.

Have you ever heard of the gun called *Big Bertha*? During the World War the Germans hauled this gun to a point about seventy-five miles from Paris and used it to hurl shells into the city. Some figures on it may illustrate how gravity must be considered in firing such a gun.

The shell, weighing about 264 pounds, was fired with a velocity of about 5000 feet a second. If there had been no air resistance, a shell fired straight upward at this velocity would have risen about 70 miles. Of course, as a matter of fact, it was not fired straight upward. The muzzle of the gun was raised to such an angle that the line of travel would carry the shell so high in the air that it could not be pulled to the ground by the force of gravity before it reached Paris. The curved path along which the shell traveled, indicated in Fig. 169, was probably as much as 24 miles above the earth at one point. An interval of about six minutes was required for the shell to travel the distance between the gun and the city 75 miles away.

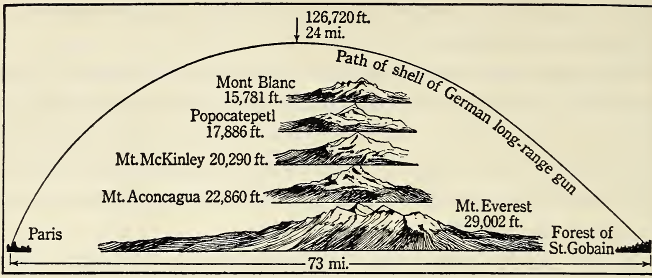


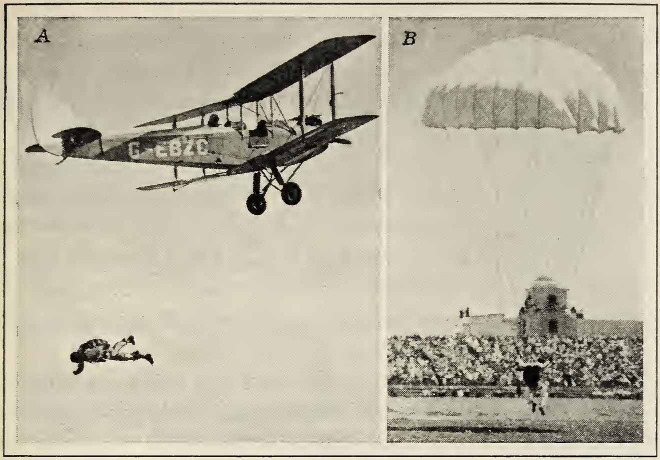
Fig. 169. What Evidence of the Force of Gravity can you find in this Diagram showing the Path of the Shell fired from *Big Bertha*?

After a diagram in the *Scientific American*

F. How does Friction oppose the Force of Gravity?

Notice that we have said in previous sections that certain things would be true "if there were no air resistance." Now we may study the effect of air resistance on the velocity of a falling body.

The experiences of parachute jumpers may teach a good deal about the effects of air friction. Men with parachutes have jumped from airplanes while flying as high as 23,000 feet. Ordinarily they open the parachute soon after leaving the plane. This checks the rate of fall, and the man floats gently to earth (Fig. 170, *B*). It was once thought that falling through the air for a great distance would cause death. In spite of this, daring experimenters have jumped from high altitudes and have delayed opening their parachutes. They have allowed themselves to fall freely for several thousand feet, as shown in Fig. 170, *A*. From these and other observations it has been found that the greatest velocity reached by a falling man is only about 200 feet per second. This is at the rate of about 140 miles per hour. You may have read of racing airplanes and automobiles that have traveled at a much greater velocity than this without injury to the drivers.



Acme

FIG. 170. The Greatest Velocity reached by a Man falling through Space is only about 140 Miles per Hour

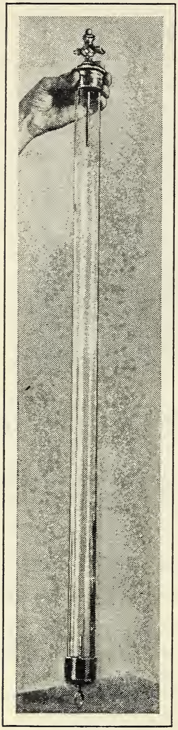
A, this jumper is making a "delayed opening" jump. *B*, air friction makes it possible for a parachute jumper to land safely

When the force of friction is equal to the force of gravity, the body falls at a uniform rate

The bullet you studied a short time ago would have fallen 10,000 feet in twenty-five seconds had it not been for air friction, and during the twenty-fifth second would have fallen 800 feet. The man would fall in similar fashion if he were not held back by friction with the air. The force of gravity causes the man to fall for a few seconds with increasing velocity. As he falls, friction becomes greater. After a few seconds the force of friction becomes equal to the force of gravity, after which the velocity is no longer accelerated and the rate of fall is uniform.

In your science workroom you may have a piece of apparatus (sometimes called a feather-and-coin tube) with which you may study the effect of air friction on falling bodies. If you do not, you can make one that will serve.

The apparatus, as you can see from Fig. 171, is merely a piece of glass tubing about $1\frac{1}{2}$ inches in diameter and about 3 feet long. It is tightly sealed and fitted up in such a way that air may be pumped from the tube.



Ewing Galloway

Fig. 171. In a Vacuum All Objects fall with the Same Velocity

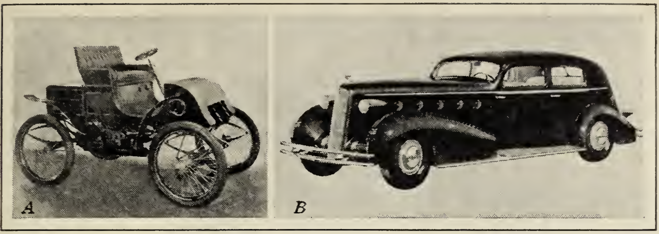
You may test the correctness of this statement by the use of a feather-and-coin tube

When you are ready to try the experiment, place a feather and a coin inside. Now seal the tube. Turn the tube so that the objects in it will fall from one end to the other. The coin falls the length of the tube in a shorter time than is required for the feather.

Remove the air from the tube with an air pump. Now turn the tube again so that the objects in the tube fall from one end to the other. Now you see that both the coin and the feather fall at about the same rate.

From this observation you may decide that if it were not for air friction, all objects would fall with the same velocity.

We are hardly conscious of the effects of friction on a slowly moving object. In the early days of the automobile little thought was given to air friction. Fig. 172 shows a model of 1912 in comparison with a model of 1935. At speeds up to 25 miles per hour friction with air is not important, but at higher speeds it is important. At 60 miles per hour the friction between the car and the air through which it passes is very great. At a speed of 60 miles an hour more than 75 per cent of the energy from the gasoline is used to overcome air resistance. Streamlining of automobiles is done in order to



Scientific American General Motors Corporation

Fig. 172. With the Development of the High-Speed Automobile, Streamlining became Increasingly Important

A, an early model; *B*, a streamline model of today. How should you like to ride in the old model at 60 miles per hour?

reduce the friction between the car and the air. Streamlining is done in the construction of the new high-speed trains. Engineers have announced that if all they know about streamlining were applied in building automobile bodies, the air friction would be reduced so much that it would be possible to get twice as many miles from a gallon of gasoline as is secured by present cars while driving at a speed of 40 miles per hour. Further developments in streamlining will require extreme changes in body designs, and it is expected that these changes will come in a short time.

Streamlining reduces friction

The force that holds back the speed of an airplane is the force of friction with the air. Airplane bodies are carefully streamlined. At higher altitudes the air is thinner and friction with the air is less. Consequently planes can travel faster at high altitudes. Fig. 173 is a chart of barograph reading made during a recent flight into the stratosphere, or upper part of the atmosphere. (A barograph is an instrument which records air pressure.) At the greatest height (nearly 12 miles) air pressure is about one fifteenth of air pressure at the surface. In this thin air friction is not nearly so great as it is near the surface. Aviation engineers be-

Friction diminishes as the air pressure grows less

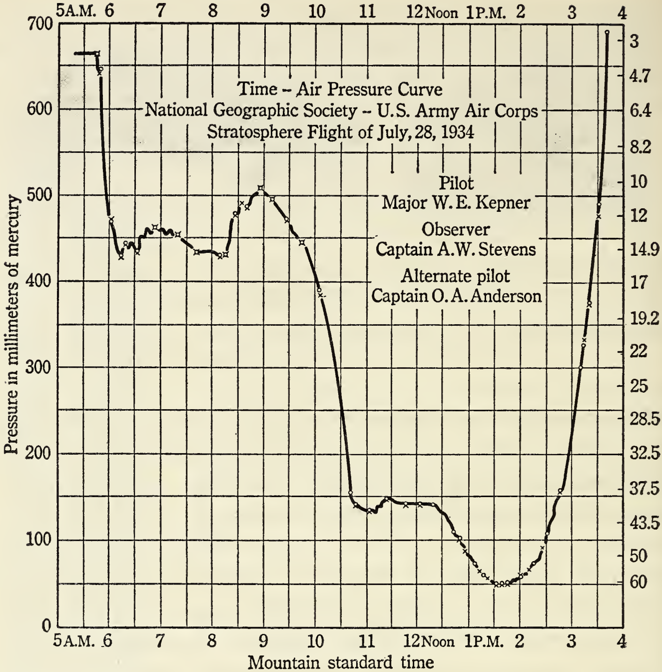


Fig. 173. At Higher Altitudes the Air is Thinner, Air Friction is Less, and Planes can travel at Higher Speed

Notice in this barograph reading how the air pressure decreased with altitude. (By courtesy of the National Geographic Society)

lieve that if a plane could be built so that it could fly at an elevation of 20 miles, they might fly at a speed of 1000 miles per hour. At this speed a flyer at the equator could just about keep up with the vertical ray of the sun.

In the study of machines we shall study the effects of forces on objects. Machinery is used to apply forces, and the forces may cause objects that are at rest to move and objects that are in motion to move faster. Forces may cause objects that are moving to move more slowly or to stop. Forces may cause objects that are moving in a

straight line to move in some other direction. The two forces with which we shall always have to reckon in the study and use of machines are the force of gravity and the force of friction. The force of gravity is nearly the same in all positions on the surface of the earth. The force of friction is not the same when conditions are changed.

The simplest definition of the force of gravity is in terms of acceleration. It is the force that gives to a freely falling body an acceleration (increase in velocity) of 32 feet (or 980 centimeters) per second each second.

Forces are constantly in evidence in the environment. Force may be defined as a push or pull that tends (1) to put an object in motion, (2) to change the velocity of a moving object, or (3) to change the direction in which an object is moving.

Can You Answer These Questions?

1. How does the force of gravity control the motion of the bodies of the solar system?

2. What is the definition of *weight*?

3. Is a pound a pound, the world around? What differences are there? What is the explanation for these differences?

4. What is the mass of an object? Distinguish between mass and weight.

5. What is meant when it is said that velocity is uniformly accelerated?

6. If there were no friction, how far would an object fall during the interval between the tenth and the eleventh second after it was released?

7. If there were no friction, how far would an object dropped from a balloon high in the air fall in twelve seconds?

8. Why is it that a man falling through the air does not reach a greater speed than about 140 miles per hour?

9. What is meant by negative acceleration?

10. What is friction? How does it affect the things of everyday life?

11. What is the purpose of streamlining? What are some of its advantages?

12. In a feather-and-coin tube the light object and the heavy object fall through a vacuum at the same rate. In the air the coin falls faster. Why is this so?

Questions for Discussion

1. Can you think of anything you do which is not to some extent helped or hindered by the effect of the force of gravity?

2. Why is it so difficult to explain just what the force of gravity is?

3. Is there any place in the universe where objects are not affected by the force of gravity?

4. Balloons have risen in the stratosphere (upper portion of the atmosphere) as high as 12 miles. Suppose a bullet were dropped from this height. If there were no friction with the air, how long would it be before the bullet reached the ground? (Because of friction with the air the velocity of the falling bullet will not be greater than 1000 feet per second.) About how long will it really take for the bullet to reach the ground? Suppose a dummy of the size and weight of a man were thrown out of a balloon at a height of 12 miles; about how much time would elapse before the dummy reached the ground?

Here are Some Things You May Want to Do

1. What do you know about the history of our weights and measures? Did the Romans use the same system that we do? the Greeks? the Egyptians? Prepare a class report or a booklet on "The Story of our Weights and Measures."

2. The regulation of weights and measures in the United States is under the direction of the Bureau of Standards. See what you can find out about this bureau, its work, and how important it is in daily life.

Chapter XVI · What are Some of the Relations between Force, Work, and Power?

In the last chapter we discussed some of the forces which are in evidence in the environment. What part do forces play in everyday life? There are many answers, but we could summarize them by saying that forces do the work of the world. Should you agree with this statement?

A. What is Work, and How is it Measured?

Notice the familiar word *work*. The word is used in many different ways. We say we do a day's work or that we work on a problem. We speak of the work of the world or the work that a factory is doing. These are loose uses of the word *work*. The statements do not have exact meaning. When an engineer speaks of work, however, he has a very definite meaning in mind, one that is exact and means the same at all times and under all conditions.

Scientifically speaking, work is done when a force moves an object through a distance. Force and distance may be measured, so work may be measured. "How?" you ask. Suppose you have on your desk a one-pound mass. As you know, this mass is a one-pound mass because a force of one pound is required to raise it against the pull of gravity. If you raise this mass through a distance of one foot against the pull of gravity, one foot-pound of work is done. Similarly if you raise it two feet, two foot-pounds of work are done. If you raise two pounds through two feet, four foot-pounds of work are done, and so on.

This concept, or idea, of the foot-pound is an important one, for in science the foot-pound is used as a *unit* for measuring work. It has under all conditions the same (or nearly the same) value.

You may say that a foot-pound is not the same at the equator and the poles, owing to the difference in the force of gravity at these points. As you have seen, however, the differences in the earth's attraction for the pound mass at different points on its surface are so slight that for ordinary purposes we may disregard them. For the present, then, you may use this unit of the foot-pound just as if it had the same value under all conditions. If you continue your work in science, you may at a later time find need for a still more exact definition of work.

Work is measured in foot-pounds

"But," you may say, "not all work consists of lifting objects against the force of gravity." True. Many times you will want to measure work done in moving objects in other directions than straight away from the earth's center. How, for example, should you measure the work done as you pull an object, say a mass of iron, over the surface of a smooth table top? As in our first example, the force required to move the mass of iron may be registered with a spring balance. You may find that one pound of force will move a mass of considerably more than one pound. In measuring work the amount of mass is not considered, only the force that is required to move it. Thus we say that a pound of force (as registered on a spring balance) moving through a distance of one foot in any direction is a foot-pound of work. A little later we shall see how many foot-pounds of work are done in driving a locomotive, an automobile, and an airplane.

Let us see if we can apply what we have learned. You may climb from the first floor to the second floor of your school building many times a day. Suppose you weigh 110 pounds and that the top of the stairway is 15 feet above the bottom. How many foot-pounds of work have you done each time? In this case 1650 (110×15) foot-pounds. A heavier person will of course do more work and a lighter person will do less work in climbing the same stairs. Do you see why?

Notice that the time taken in climbing the stairs does not affect the *amount* of work done. Whether you climb the stairs in thirty seconds or three minutes, you still do the same *amount* of work; that is, you climb the stairs. The time is not considered in measuring the work. The amount of work and the amount of power, however, are two different things, as you will see in the next section.

B. What is Power, and How is it Measured?

Just as in the case of the word *work,* the word *power* is used in many different ways. We say that an automobile has tremendous power, that the power of a new locomotive is far beyond any which has gone before, or even that a certain ruler has great power over his subjects. Obviously the word *power* does not mean the same in each of these cases. The word *power* too needs to be defined in more exact terms. Can this be done?

Power is the rate of doing work

In a scientific sense *power* is defined as "rate of doing work." Horsepower (often written H. P.) is the unit in common use. Originally a horsepower was considered to be the rate at which a horse works; but since different horses work at different rates, the definition is not very helpful. Today the scientific definition of 1 horsepower is work at the rate of 550 foot-pounds per second. This is the same as 33,000 foot-pounds per minute. You may wish to learn at how many horsepower you can work.

Look at the figures you secured for the stair-climbing illustration. Suppose you find that you can climb these stairs in thirty seconds. You would be working at the rate of 1650 foot-pounds in thirty seconds, or 55 foot-pounds in one second. Since 1 horsepower is work at the rate of 550 foot-pounds in one second, you are working as you climb the stairs at the rate of $\frac{1}{10}$ horsepower. Could you work faster than this?

You may be able to climb the stairs in five seconds. In this case you are working at the rate of 1650 foot-pounds in five seconds, or 330 foot-pounds in one second. This is at the rate of $\frac{6}{10}$ horsepower. If the stairs were very, very high and you were to continue for a long time, you would soon slow down to a rate of about $\frac{1}{8}$ or $\frac{1}{10}$ horsepower. A strong man may work through an eight-hour day at the rate of about $\frac{1}{8}$ horse power.

Horsepower is a common unit of measuring rate of work

Do you now see the difference between the unit of work and the unit of power? One engine may do 3,300,000 foot-pounds in one hundred minutes; another engine may do this same amount of work in one minute. The *amount* of work is the same, but the first engine is working at the rate of 1 horsepower (33,000 foot-pounds per minute) while the second engine is working at the rate of 100 horsepower (3,300,000 foot-pounds per minute).

Other common observations may be used to make more vivid the definitions we have given. For example, what is the horsepower of falling water? A pound of water falling 1 foot is thought of as doing the same amount of work as is done in raising a pound of water 1 foot. Suppose, then, that water is running over the falls at the rate of 3300 pounds in a minute and is falling 10 feet. In this case the power of the falls is 33,000 foot-pounds per minute. This is at the rate of 1 horsepower. The power plant of Boulder Dam will, when completed, develop some 663,000 horsepower. The dam is about 700 feet high. With these figures can you tell how many pounds of water must pass over the dam in one minute?

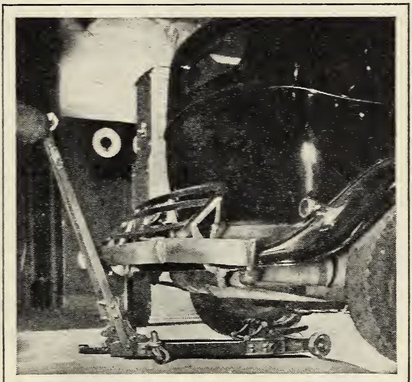
C. How may we use Simple Machines to do Work?

When we use the term *simple machines,* we are not thinking of automobiles, locomotives, or the types of machines used in manufacturing plants. These are machines,

but they are not simple. Rather we are thinking of other types of machines, including some things used in everyday life which many people do not consider machines at all. For example, a tire must be changed on the family car. You take out a jack and go to work. The jack, as you can see from Fig. 174, is usually a type of lever, which, in turn, is one type of simple machine. If you live in a city,

There are many simple machines in everyday use

you may have seen men lift a piano from a truck and through a window on the fifth or sixth floor of an apartment house. The principal part of their equipment is a block and tackle like the one shown in Fig. 175. This is a set of pulleys blocked together. A pulley is another type of simple machine. There are others. When an automobile is being driven in low or second gear, certain wheels called gear wheels are being used. These gear wheels are really simple machines.



Ewing Galloway

Fig. 174. A Common Jack is One Type of Lever and thus a Simple Machine

On what does the efficiency of the jack depend?

So you see all around you examples of simple machines. We have named three. These are not all, but are used merely as examples. Because of their importance to the development of work and power it is necessary that we learn something about simple machines and their use. Perhaps the easiest way to do this is to study some typical cases of their use.

Imagine that you are a visitor to a large stone quarry. In one corner two men are standing near a block of stone

which has been sawed into a mass 4 feet long, 1 foot wide, and 1 foot thick. These 4 cubic feet of stone weighing, say, 600 pounds, are to be loaded on a truck and taken to the near-by city. The truck arrives, and the driver unloads certain tools. There are a steel bar, a block and tackle, some pieces of chain, and some rope. At the end of the truck is a derricklike arrangement. The immediate problem is to get the stone off the ground sufficiently to permit placing a length of chain around it. After that is done, the block will be rigged up with rope and attached to the derrick. The stone will then be lifted into the air and swung onto the truck. How do the men begin? Study Fig. 175.

Fig. 175. Heavy Objects may be easily moved with the Aid of Simple Machines

First they use their iron bar, which is a simple machine of the lever type. One end of the bar is pushed under the edge of the stone. The other end of the bar is raised so that a block of wood may be set in the position shown in the picture. This block of wood serves as a fulcrum, or support for the lever. Notice that the fulcrum is close to the stone. In this condition a small force downward on one end of the bar exerts a powerful force upward at the other end of the bar. This is important; for the stone weighs 600 pounds, and a force of about 300 pounds, that is, half the weight of the stone, is required to raise one end of the stone sufficiently to slip a chain under it.

The lever is a simple machine

Examine with some care the process used in raising this one end of the stone. Suppose the fulcrum is set just 6 inches from the end of the block. Suppose too that it is just 5 feet from the fulcrum to the end of the bar where the force is applied. You could show by measurement that a force of about 30 pounds applied at the end of the lever will be sufficient to raise the load of 300 pounds.

Notice the advantage that is gained through the use of the lever. In this case an effort of 30 pounds balances a resistance, or opposing force, of 300 pounds. The ratio of resistance to effort is called mechanical advantage. With this lever the mechanical advantage is 10 ($\frac{300}{30} = 10$). In other words, a force of 30 pounds is sufficient to move a resistance of 300 pounds.

But how much work is done at each end of the lever? How does the work done in pushing the end of the lever down compare with the work done in raising the load? In other words, how does the work put into the machine compare with the work that comes out of it? Let us measure the force applied and the distance through which it moves.

The principles of simple machines may be illustrated with a lever

It will be necessary to raise the block at least 2 inches before a chain can be slipped under it. Two inches is $\frac{1}{6}$ foot. The work done in raising 300 pounds through $\frac{1}{6}$ foot is 50 foot-pounds ($300 \times \frac{1}{6} = 50$). The force of 30 pounds, however, which is applied at the free end of the lever moves through a much greater distance as the block is raised. Measurement would show that this force moves through 20 inches, or $1\frac{2}{3}$ feet, while the load end of the lever is raised 2 inches. Therefore the work done at the free end of the lever is also 50 foot-pounds ($30 \times 1\frac{2}{3} = 50$). In other words, the work done where the force is applied at the end of the lever (50 foot-pounds) is just equal to the work done in raising the load. This illustrates one principle of machines.

This principle might be stated in different ways. For example, we might say that the effort times the distance through which it moves is equal to the resistance times the distance through which it moves. Is this a correct statement? Can you support it? Again, we might say that the work done to the machine is equal to the work done by the machine. In the lever it is easy to see these relations. In other simple machines it is not easy, for much of the effort is used to overcome friction.

If you wish to study these relations further, you can set up additional problems for yourself. What would happen if you moved the fulcrum nearer the edge of the stone? Suppose the crowbar were longer?

From these observations of the lever two important principles may be derived:

1. When the effort is applied to the longer arm of the lever, the mechanical advantage is greater than 1.
2. The work done (foot-pounds) by the effort is just equal to the work done in raising the load. (There is but little loss on account of friction in this simple lever.)

Let us go on with our observations of the men and their problem of raising the stone and getting it onto the truck.

The pulley is another type of simple machine

They of course did not stop to figure out scientifically just how long their lever should be or where the fulcrum should be placed. They merely pushed the fulcrum to a point where effort applied to the lever would lift the stone. After it was lifted, one of the men slipped a chain under the stone and fastened the chain on top. The men then arranged the block and tackle. Let us look at it. The simple machine used here consists of two blocks of two pulleys each, properly threaded with strong ropes, as shown more clearly in Fig. 176. One of the blocks is attached to the derrick, and the other is attached to the chain. As the pulleys hang from the derrick, you see four strands of rope between

the two blocks. Two of the men take hold of the loose end of the rope and start pulling it through the pulleys. As they pull, the stone is slowly raised. Evidently it is not difficult for two men to raise a load of 600 pounds with a block and tackle like this one. After a few minutes' work the stone has reached the proper height. The men stop pulling, and swing the stone into the truck. Then they release the rope, and the stone is lowered to the floor. The block and tackle is removed, and the tools are placed back on the truck.

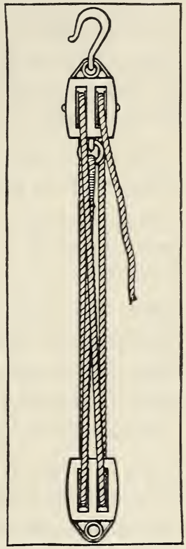


Fig. 176. The Number of Strands of Rope between the Two Blocks of a system of Pulleys is Equal to the Mechanical Advantage of this simple Machine

What is the mechanical advantage of this system of pulleys?

But let us study this block and tackle a little more carefully and see if we can determine why the men could lift such a heavy load with it.

You noticed that one man with a lever rather easily raised the block of stone 2 inches. With the block and tackle, however, two men found it a harder job to raise the stone. Why this difference? There is of course considerable friction between the parts of this simple machine, but we find by measurement that, if friction is ignored, a force (a pull) of 150 pounds would be necessary to support the weight of the stone. The resistance, then, is four times the effort. The mechanical advantage is therefore 4. What was it in the case of the lever?

Again, by measurement one could find that it is necessary to pull 4 feet of rope through the pulleys shown in Fig. 176 in order to raise the stone 1 foot. The effort moves through 4 feet while the resistance moves 1 foot. The ratio of the force distance to the effort distance ($\frac{4}{1}$) is the same as the mechanical advantage.

The work done in raising the stone 1 foot is 600 foot-pounds ($600 \times 1 = 600$). It may be necessary to raise the stone 5 feet in order to load it. The work done in raising a load of 600 pounds to a height of 5 feet is 3000 foot-pounds ($600 \times 5 = 3000$). In order to raise it 5 feet, however, 20 feet of rope must be drawn through the pulleys. In other words, the effort acts through a distance of 20 feet ($150 \times 20 = 3000$).

On account of friction it is obvious that considerable effort will be required to pull the rope through the pulleys.

The efficiency of a machine may be measured

In practice an effort of 300 pounds, instead of 150, might be required to raise this 600-pound stone. If this were the case, the work done in raising this stone would be 6000 foot-pounds ($300 \times 20 = 6000$). On account of friction 6000 foot-pounds of work must be applied in order to do 3000 foot-pounds of work on the stone.

The ratio of the work done on the resistance to the work done by the effort is called the efficiency of the machine. This efficiency is expressed as a percentage. Such a ratio tells what per cent of the work done by the effort is really applied to raising the load and how much of the work is lost in friction. In this case the efficiency of the block and tackle is 50 per cent.

A principle illustrated by the block and tackle is the same as one of the principles illustrated by the lever. Disregarding friction, the work done by the force applied to the rope is just equal to the work done in raising the load. In this case a considerable amount of the work done is used to overcome friction.

When the stone is suspended from the pulleys, you may see that the weight is really supported by four strands of rope. The strain on each strand is therefore one fourth of 600 pounds, or 150 pounds. An effort of 150 pounds on the loose end of the rope is therefore sufficient to support the weight of the stone.

We may summarize these observations on the pulley system:

1. The mechanical advantage is greater than 1.

2. The work done by the effort is equal to the work done in raising the load plus the work done in overcoming friction.

3. Efficiency is the ratio of the total work done by the effort to the work accomplished in raising the load. The efficiency of the block and tackle is low in comparison with the lever.

4. The number of strands of rope between the two blocks is equal to the quotient obtained by dividing the load, or resistance, by the effort. This is the mechanical advantage of the machine.

You have seen many applications of levers and pulleys, but in all of them the general principles are the same. The mechanical advantage is the ratio of resistance to effort. It is also the ratio of the effort distance to the resistance distance. With the lever it is the ratio of the length of the two lever arms. With the pulleys it is equal to the number of strands supporting the resistance.

How much advantage may be gained through the use of a lever? If the short lever arm were made shorter or the long lever arm longer, obviously the mechanical advantage would be greater. Archimedes, a scientist of ancient Greece, said that if he could have a lever that was long enough and strong enough, and a fulcrum to support it, he could move the earth.

A lever may have a great mechanical advantage

In a garage you have probably seen a mechanic push a heavy jack under the rear of a large automobile or a truck and easily raise the wheels off the floor. The jack is a lever. When the handle is pushed down, the car is raised only a very little. The handle must be raised and lowered several times before the wheels are off the floor. The weight that is raised may be 2 tons or even more. Probably an effort of 50 pounds applied to this jack will raise 2 tons (4000 pounds). This requires a mechanical advantage of 80

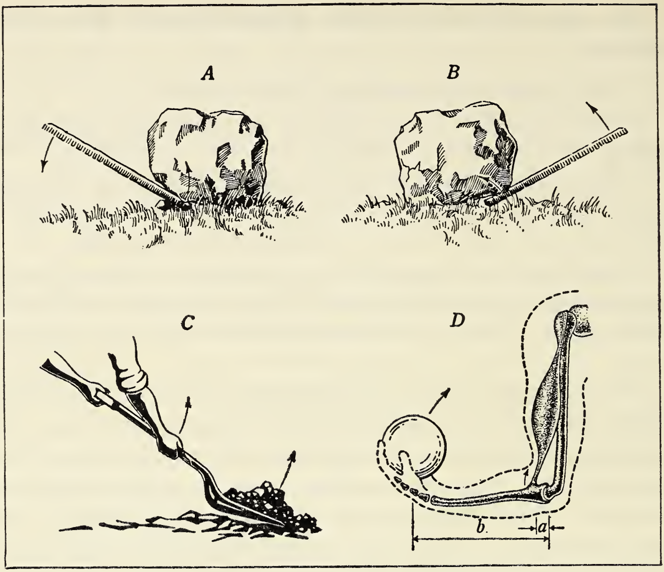


FIG. 177. There are Three Types of Levers

A, a lever of the first class; *B*, a lever of the second class; *C* and *D*, levers of the third class. Do you know of any other common applications of these various levers?

($80 \times 50 = 4000$). Therefore the lever arm must be 80 times longer than the weight arm. If the lever arm is 60 inches long, the weight arm must be $\frac{3}{4}$ inch long ($60 \div 80 = \frac{3}{4}$).

There are three types of levers

So far we have talked about levers generally, as though there were only one kind of lever. Levers, however, fall into three different classes. In the observations made so far the fulcrum has been between the weight and the force. Look at Fig. 177, *A*. This is a lever of the first class and is probably the one with which you are most familiar. It is the one used by the men in moving their stone.

What is a lever of the second class? You may place

one end of a bar under some heavy object, such as a stone, and raise the stone as shown in Fig. 177, *B*. In this case the fulcrum is at one end of the bar, and the weight (resistance) is between the fulcrum and the effort. This is a lever of the second class. The mechanical advantage is figured in the same manner as the mechanical advantage of a lever of the first class. With a lever of the second class the effort arm is the length of the lever bar. The resistance arm is the distance from the end of the bar (the fulcrum) to the position on the bar at which the force is applied to the weight. In Fig. 177, *B*, the bar is 5 feet, or 60 inches, long. The weight to be raised (resistance) is 14 inches from the end of the lever. The mechanical advantage is 15. With this lever an effort of 4 pounds will raise a load of 60 pounds. A lever of the second class is useful when the load is to be moved through a very short distance.

Different classes of levers have different mechanical advantages

There is also a third-class lever. In this the force is between the fulcrum and the weight. The bones of the forearm are a good illustration of a third-class lever. The fulcrum is at the elbow joint; the hand is the weight, or resistance. The effort is applied through the muscle which is attached to the forearm and to the shoulder. The effort is applied between the joint (the fulcrum) and the hand (resistance). Study Fig. 177, *D*. In this case the effort arm is the very short distance between the elbow joint (see *a* in Fig. 177, *D*) and the position at which the muscle is attached to the forearm. The resistance arm is the distance between the joint and the hand (see *b* in Fig. 177, *D*). The effort arm may be 1 inch, and the resistance arm may be 20 inches. In this case an effort of 20 pounds applied by shortening the large muscle of the arm would raise a weight of but 1 pound. The mechanical advantage is $\frac{1}{20}$. The muscle in the arm is shortened about 2 inches in bending the arm from a straight position until the hand is near the shoulder. The position on the bone

at which the muscle is attached to the forearm moves through a distance of about 2 inches while the hand moves through a distance of about 40 inches. Can you "muscle" a 10-pound weight? As you do this, an effort of 200 pounds is exerted by the muscle.

A shovel is another example of a third-class lever (Fig. 177, *C*). The distance through which the weight (resistance) on the shovel is moved is greater than the distance through which the effort moves.

With levers of the first class and second class as they are commonly used the mechanical advantage is more than 1 and may be very much more than 1. With these levers a heavy weight may be moved by applying a small force. The force moves through a large distance while the weight moves through a short distance. The mechanical advantage of a lever of the third class is less than 1. With a lever of the third class a weight may be moved through a great distance, but a strong force must be applied to move it. In each case, however, the principle of work is the same. The product of the force times the distance through which it moves is the same as the product of the weight times the distance through which it moves.

There are many common applications of levers and pulleys. These simple machines and some others are parts of the complex machines which are seen in factories and locomotives.

Earlier in this chapter we spoke of certain simple machines other than levers and pulleys. Let us look at some of them.

The inclined plane is a simple machine

What is the mechanical advantage of an inclined plane? We may consider again the task of raising a heavy stone block into a truck and think of another way to do it. This time we may push it up an inclined plane, as shown in Fig. 178. Some strong planks may be used for the plane. Suppose it is 2 feet from the ground to the floor of the truck and that the

Fig. 178. The Inclined Plane is a Simple Machine

How does its mechanical advantage compare with that of other simple machines?

planks are 10 feet long. The stone is raised with a lever, and rollers are placed under it. If there were no friction, an effort of 120 pounds would be sufficient to push a stone block weighing 600 pounds up an inclined plane 10 feet long and 2 feet high. There is friction in this type of machine, but the rollers reduce it so that only a little more effort than this will be required. Two men may do the job easily. The mechanical advantage of this inclined plane is 5, for an effort of 120 pounds will raise a weight of 600 pounds.

The mechanical advantage of an inclined plane, then, may be figured from measurement of the plane. It is equal to the length of the plane divided by the height. If the plane used to load the truck were shorter, it would necessarily be steeper. In such a case the mechanical advantage would be less. A greater force would be required to push the stone up the plane and onto the truck. Set up some problems for yourself to illustrate this.

A set of gear wheels is a simple machine

What is the mechanical advantage of a set of gears? The mechanical advantage of a set of gears is greater than 1 if the wheel to which the force is applied is smaller than the wheel into which it fits. Let us illustrate. In one set of gear wheels in Fig. 179 the smaller wheel has eight teeth and the larger one has twenty-four teeth. The small wheel therefore turns three times while the large wheel turns once. The mechani-

cal advantage of this set of gears obviously is 3. If there were no friction, an effort of 1 pound applied to the small wheel would be passed on as a force of 3 pounds by the large wheel. If there were twelve teeth on the small wheel and twenty-four teeth on the large one, as shown in the other set illustrated in Fig. 179, the small wheel would turn twice while the large one turns once. An effort of 1 pound applied to the small wheel would be passed on, if there were no friction, as a force of 2 pounds from the large wheel. The mechanical advantage of this set is 2. If the two wheels had the same number of teeth, they would both turn with the same speed. A force of 1 pound applied to one gear wheel would be passed on, if there were no friction, as a force of 1 pound. The mechanical advantage in this case would be 1.

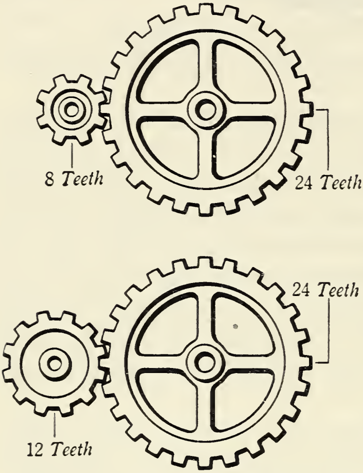


Fig. 179. A Set of Gear Wheels is a Simple Machine

How is the mechanical advantage determined?

Machines are instruments for using energy. Forces are applied as efforts, and resistances are overcome. Compound machines are combinations of simple machines. Steam engines, gasoline engines, manufacturing machinery, and all other compound machines are merely combinations of levers, pulleys, cogwheels, and other simple devices. In all of them forces are applied, work is done, and the rate at which work is done (that is, power) may be measured. Forces with their origins in the sun's rays flow through the machines and do the work of the world.

Standards may be set up by which work and power may be exactly defined. Simple machines, such as the lever, pulley, plane, and gear, are useful because of their mechanical advantage.

Can You Answer these Questions?

1. What is the scientific definition of *work*? What is a foot-pound?

2. What is the scientific definition of *power*? What is a horsepower?

3. How can you find the mechanical advantage of a machine?

4. Why is climbing a flight of stairs work? Does a heavier person do more work than a lighter person?

5. What relationships are there between the unit of work and the unit of power?

6. What are the chief differences between levers of the first, the second, and the third class? What relationship is there between these differences and the relative efficiency of the three types?

7. What is meant by the mechanical advantage of a simple machine?

8. Is a pulley as efficient a simple machine as a lever of the first class? Prove your answer.

9. What is the relation between friction and the efficiency of a machine?

10. How may the efficiency of an inclined plane be determined?

11. What determines the efficiency of a set of gears?

12. How many of the principles of the lever can you name and demonstrate? of the pulley?

Questions for Discussion

1. Why does it hurt worse when you catch your finger in the hinge of a door than when you catch it in the space by the latch?

2. May a fat person get tired "just carrying around his own weight"?

3. Does one do more or less work in pushing a five-pound box along the floor than in raising it from the floor? Can you defend your answer?

4. Why does the horsepower at which you are working increase as you run faster and faster up a flight of stairs?

5. What are some of the difficulties in reducing friction in machinery? Could there be a frictionless machine?

6. Are all automobile jacks based upon the principle of the lever?

7. Can you think of any evidence to support the theory that some types of simple machines were used before other types?

Here are Some Things You May Want to Do

1. Make an exhibit of models illustrating some of the simple machines described in this chapter. Label them accurately, and prepare descriptions of each so that a person unfamiliar with their principles may understand them. If you cannot make the models, a number of illustrated charts would help.

2. Prepare a chart like the one that follows, and complete it.

	Common Mechanisms used in the Home	**Common Mechanisms used in Industry**
Levers of the first class .		
Levers of the second class		
Levers of the third class .		
Pulley		
Inclined plane		
Gears		

3. Read again the principles of the lever and pulley and see if by a number of problems in mathematics you can demonstrate their application.

4. Find a picture of some machine such as an automobile, a locomotive, or an airplane, and see how many types of simple machines play a part in its operation.

5. Describe the lever that you might use to raise a load of 1000 pounds.

Chapter XVII · What are Some of the Characteristics of Energy?

In this unit you have so far considered some questions of force and work. In this chapter we introduce another factor, that of energy. What is energy? To answer this question let us review some of the things we have found out about force and work.

We have said that force is a push or a pull. The one force on the earth which serves as a standard of measurement for all other forces is that of gravity. The measure of force, then, is really the pull required to move an object in a direction away from the center of the earth. How about work? You will recall that work is done when a force is moved through some distance.

Evidences of energy are all about us

But what is energy? There are evidences of energy all about us. There is energy in the wind, in flowing water, — in fact, in everything that moves. There is energy in food and fuels. It is released as foods are oxidized (combined with oxygen) in living cells and as fuels are oxidized, as in burning. Thus you may recognize energy in moving objects, in chemical changes, in sound waves, and in heat, light, radio waves, and X rays.

To define energy is a more difficult problem. Like gravity, energy cannot be defined in simple language. Perhaps the best way of defining energy would be to say that a thing has energy if it can do work, that is, if it can exert a force through a distance.

There is thus an obvious relation between energy and work. The same unit, the foot-pound, is used in the measurement of work and energy. How much energy is there in a pound of coal? The answer to this question may be made in terms of the amount of work it will do.

A. What is Kinetic Energy, and What is Potential Energy?

The energy of falling water and the energy of coal seem quite unlike, yet they are the same in that both can do work. Falling water has energy because it is in motion. It may fall upon and turn a water wheel. The wheel itself may be attached to the shaft of a dynamo. In this case the energy of falling water would be changed into electrical energy. The flowing water is energy of motion. Such energy is called kinetic energy. The word *kinetic* is derived from a Greek word meaning "to move." Every moving object, be it a molecule, a bullet, or a train of cars, has kinetic energy (see Fig. 180).

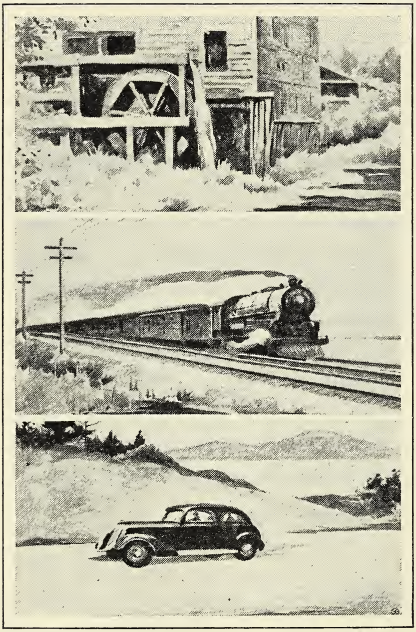


Fig. 180. Every Moving Object has Kinetic Energy

The energy of coal is not in evidence except as the coal burns. As the burning goes on, energy is released from the coal. You may think of it as having been stored in the coal. Such stored energy is called potential energy. The word *potential* is derived from a Latin word which means "having power." Notice that, as the stored, or potential, energy is released, it becomes kinetic. This is important, and we shall say more about it in just a moment.

FIG. 181. There is Potential Energy in the raised Pile Driver, the Wound Clock Spring, the Stick of Dynamite, and the Foods

There are many common illustrations of potential energy. A weight that has been raised has potential energy because of its position. When released, it falls and strikes with a force. There is potential energy in a clock spring after it has been wound. This energy is slowly released to turn the hands of a clock. There is potential energy in gunpowder, which is released when the powder explodes. The energy of foods is potential, being released as the food is oxidized in the cells of the body. (See Fig. 181.) Since energy plays such an important part in everyday life, it is of course essential that it be measured. Can this be done with the accuracy that force or work can be measured?

Let us take an illustration showing both types of energy. Through this illustration we can not only trace the relationships between energy and work but can also show how energy may be measured.

Consider a gun shell loaded with powder and carrying a projectile weighing exactly 1 pound. The energy of the powder in the shell is potential, but is changed to kinetic when the gun is fired. And now suppose that the gun is fired straight upward, that is, in a direction opposite to the force of gravity. Suppose, too, that the energy of the exploding gunpowder is sufficient to give the projectile such a push that it leaves the gun with a velocity of 3200 feet per second. From your study of acceleration you know that the force of the earth's attraction for the projectile slows its speed 32 feet per second each second as it rises. If there were no air resistance, the projectile would continue to rise for a hundred seconds and in this time would rise to an elevation of 160,000 feet. Since the projectile weighs 1 pound, the work done in raising it to this height is 160,000 foot-pounds. Do you see why?

Potential energy may become kinetic energy, and kinetic energy may become potential

But what happens as the projectile moves upward? It loses kinetic energy, for it loses speed as it moves higher and higher. It gains potential energy, for the higher it goes the harder it will strike (or push) against the earth when it falls. At an elevation of 160,000 feet it has lost its kinetic energy. All this (except what has been used to overcome air resistance) has been changed to potential energy.

Now the projectile has reached the top of its path. On account of the earth's attraction for it the projectile immediately starts to fall. It now gains speed at the rate of 32 feet per second each second as it falls. Therefore the kinetic energy increases as it falls. If there were no air resistance, the projectile would strike the ground moving with the same velocity as when it left the gun barrel. It has its greatest potential energy (160,000 foot-pounds) when it is at its highest position. As it falls, it increases in speed, regaining kinetic energy as it loses potential. It loses 1 foot-pound of potential energy and gains 1 foot-

pound of kinetic energy for each foot it moves closer to the earth. When the projectile finally strikes the earth, it has once more the greatest amount of kinetic energy. Perhaps Fig. 182 will help to make this clearer for you.

Do we now have any measure of energy? Consider the powder in the shell. There were 160,000 foot-pounds of energy in the powder in the cartridge, for it was sufficient to do 160,000 foot-pounds of work. In the observations, then, you see a cycle of change. Energy is changed from potential to kinetic as the powder explodes; from kinetic to potential as the projectile rises; from potential to kinetic as it falls. Study Fig. 182 again.

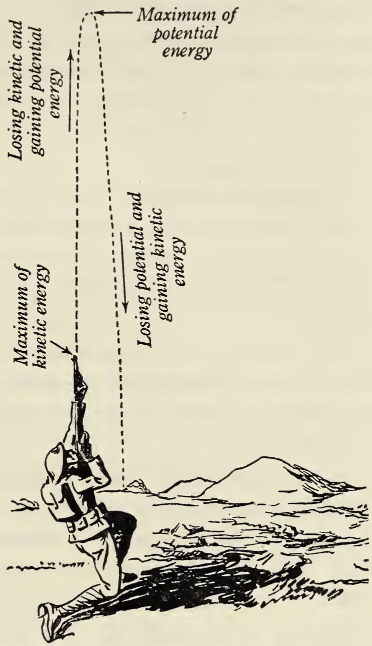


Fig. 182. Potential Energy may become Kinetic Energy, and Kinetic Energy may become Potential

Can you trace these changes in the firing of a gun?

Perhaps you would like to know what happens to this kinetic energy when the projectile strikes the ground. The energy of a falling object is not destroyed. On the contrary in your further study you will learn that most of the kinetic energy of a falling body is changed into heat when the body strikes the ground.

In explaining the cycle of change which occurs as a projectile rises and falls we have, as you notice, assumed that there is no friction involved. As a matter of fact, one finds that in the measurement of energy, as in the measure-

ment of work, recognition must be made of the effects of friction. Energy is really used to work against friction as well as against gravity. Thus in the construction of machinery every effort must be made to reduce the friction between moving parts and to reduce friction with air. In an automobile, for example, the less the friction between moving parts of the machinery and the less the friction between the automobile and the air the greater the distance the automobile may be driven by the energy of a gallon of gasoline.

Energy must be used to overcome the effects of friction

This introduces a very interesting question, and one which man for many years has tried to solve in a practical way. Can friction be reduced to zero? Can there be a frictionless machine? If you will consider what you have learned of the effect of friction on motion, you will see that a frictionless machine would be a machine with perpetual motion, that is, one which would keep on going indefinitely.

Can a perpetual-motion machine be built? The United States Patent Office refuses to consider such machines unless a working model is submitted. Why is this required? Fig. 183, *A*, is one of the many designs that have been offered by enthusiastic workers. The wheel, according to the man who built the machine, would be made to turn in the direction indicated by the arrow through the action of the balls rolling to the outside and thus exerting greater leverage upon the wheel. What is wrong with this idea? Why would such a machine not work? Study the illustration. Obviously for every ball that rolls from the center outward to the rim of the wheel another ball must roll from the rim inward. Consequently the balls contribute nothing to keeping the wheel turning. In fact, they increase the friction within the system. The wheel would really run longer without the balls.

Fig. 183, *B*, shows another design for a perpetual-motion

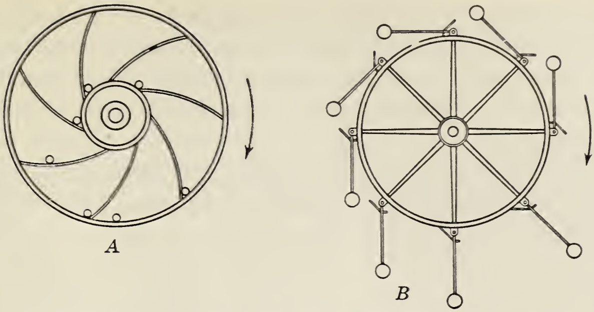


Fig. 183. Scientists believe that there can be No Such Thing as a Perpetual-Motion Machine

The ones shown are but two of the many machines which have been tried. By further reading extend your study of perpetual-motion machines. Make drawings of other schemes that have been tried

machine. This one is supposed to work on a similar principle to that shown in *A*. What is wrong with this idea? And so with every so-called perpetual-motion machine. Friction cannot be done away with completely.

Energy cannot be created or destroyed

There is a principle of physics which says that energy can be neither created nor destroyed. Within every moving object there is some friction. Therefore energy must be furnished to a machine to keep it going. Scientific men decided many years ago that there can be no such thing as a perpetual-motion machine, for energy cannot be created by machinery.

B. What is the Origin of Energy?

If you were to answer this question on the basis of your previous science work, you would probably say, "Energy comes from the sun." Perhaps now you would like some proof of this. That the sun's rays (solar radiation) are a form of energy may be demonstrated in a very direct manner by means of a radiometer. Jewelers frequently display

these instruments in their show windows to catch the eye of those who pass by. This little instrument consists of a part that looks somewhat like a paddle wheel mounted inside a sealed glass container from which most of the air has been removed (Fig. 184). One surface of each blade is coated jet black; the other surface is bright. When the radiometer is placed in sunshine, the wheel within it begins to turn. A natural conclusion is that the rays of the sun possess energy. Can this be explained?

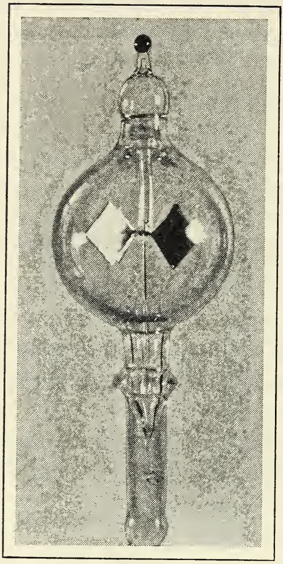
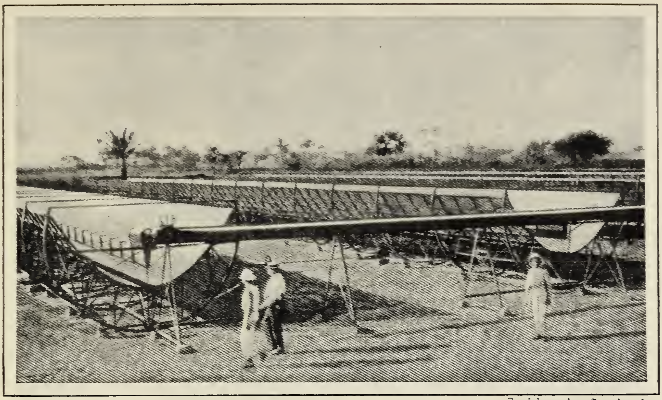


Fig. 184. Energy comes from the Sun

How does this fact help to explain the action of a radiometer?

A black surface does not reflect the sun's rays; a bright surface does. On the black surface, energy from the sun is turned into heat. Heat, you may remember, is the energy of moving molecules. The molecules composing the matter of the blackened surface take on more energy than those of the brightened surface. There is some air in the radiometer; and as the molecules of the gases of the air collide with the blackened surface they are heated; that is, they gain in energy. Molecules of the gases are therefore bombarding the blackened surface with more force than molecules are bombarding the bright surface. Consequently the shaft turns round and round. Notice that it always turns as it would if the pushing force were against the black surface. When it is removed from the influence of the direct rays, it stops turning. Does this explain what you see in a radiometer?

There is energy in the rays of the sun



Smithsonian Institution

Fig. 185. Solar Engines have been built so that the Energy of the Sun is used to run Machinery

This picture shows a large area of mirrors set so as to focus the sun's rays on pipes carrying water

The amount of energy from the sun that falls upon the tiny blades of the radiometer is of course small; but the total amount of energy from the sun is enormous, and directly or indirectly it serves nearly all the needs of man.

There are many evidences that solar radiation produces heat. You avoid the bright sunshine in summer to keep cool, and you seek the bright sunshine in winter to keep warm. You have probably demonstrated with a lens that rays of the sun do produce heat. They may be focused to a point by means of the lens in a reading glass. The heat produced at the point may be sufficient to set fire to paper.

Solar engines have been built through which the energy from the sun is used to run machinery. Sun's rays covering a large area are focused by means of mirrors upon the boiler of a small engine. Fig. 185 is a photograph of the mirrors set to collect the sun's rays for an engine that was used for a time in the Sahara Desert.

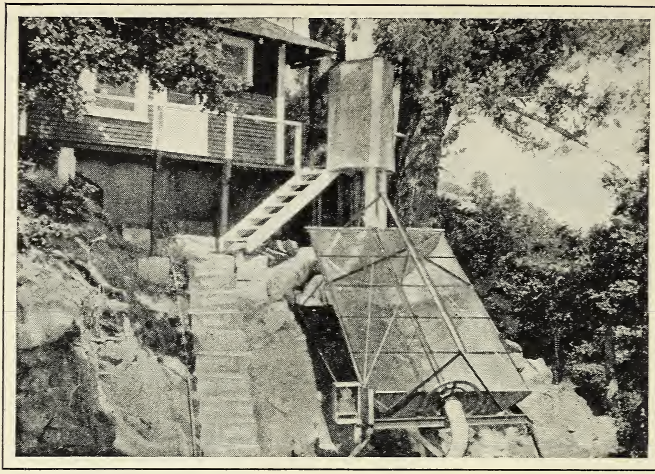


FIG. 186. The Solar Cooker designed by Dr. C. G. Abbot of the Smithsonian Institution uses the Energy of the Sun for Heat

Do you see how it works? The cooker is at the top of the steps. Look at Fig. 187

Solar radiation produces heat

By the use of this engine the rays of the sun were focused on pipes carrying water. The radiant energy, changed to heat, was sufficient to produce steam and run an engine used to pump water for irrigation. Some other engines have been made, but they have not been successful. They are not good enough to be used in competition with engines that derive energy from coal.

Another illustration of energy from solar radiation is found in the solar cooker. The one in the picture (Fig. 186) was made by Dr. C. G. Abbot, director of the Smithsonian Institution. By using a mirror in the shape of a cylinder he focused 90 square feet of sun's rays upon a tube $1\frac{1}{4}$ inches in diameter. The tube was connected to a tank that was filled with heavy engine oil. The sun's rays heated the oil in the tube, and it circulated in such a way as to heat all

the oil in the reservoir. Fig. 187 shows this. An oven was so constructed that oil circulated by convection through pipes surrounding it. It was carefully insulated and remained hot enough through the night to be used for baking.

From these and other similar attempts we can come to the conclusion that there is really an enormous amount of energy in solar radiation. If all the energy from a beam of 1 square yard could be changed without loss into mechanical work, it would do work at the rate of more than a horsepower. In other words, there is enough potential energy in a beam that covers 1 square yard to raise 550 pounds one foot in a second and to keep up work at this rate as long as the sun shines.

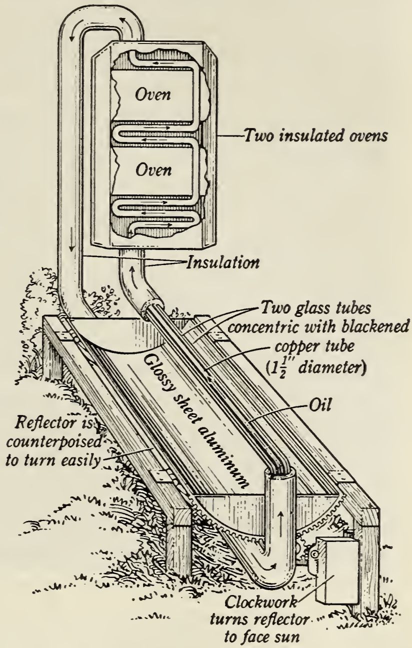


FIG. 187. The Oil in the Tube of the Solar Cooker, after the Sun has heated it, circulates and heats the Ovens

The oil circulates by convection

The disappointing feature in all these efforts to use solar radiation is the fact that the energy cannot be changed to another form without great loss. In fact, no inventor so far has been able to use more than 3 per cent of the total. Instead of 1 horsepower from the sun's rays on a square yard the rays on about 30 square yards are needed in order to develop this much power.

It is reasonable to suppose that men will sometime use energy from the sun to do work. Certainly there is an enormous amount coming to us. Each square mile receives energy at the rate of more than 3,000,000 horsepower while it is exposed to the sun. In the United States we are using energy in industry at the average rate of about 40,000,000 horsepower. Suppose that the average time of sunshine is three hours per day through the year. The total solar energy on about 110 square miles would be sufficient to supply our present industrial needs if it could be changed into usable form without loss. But unfortunately it cannot be. It is quite possible to believe that our engineers may build great systems of mirrors for taking from the total energy of solar radiation a sufficient amount for all our needs. Such an enormous engineering scheme need not be launched immediately. We have an abundance of coal and oil. But some day, when our stocks of stored energy are exhausted, the problem may have to be faced.

In the future solar radiation may be a direct source of energy for industry

In all these observations we should remember that the sun's rays are not heat. They are a form of energy (capacity to do work) that is readily changed to heat. These rays pass through the space between the earth and the sun. Yet the temperature of outer space is certainly very much colder than it is anywhere on the surface of the earth. How may this be explained? Heat is a property of matter; and since there is almost no matter in the space between the planets, there is almost no heat. The energy of the sun's rays is converted into heat only when the rays fall upon matter.

Let us once more look at the sun, the source of the earth's energy. The sun is an immense mass of hot matter. The temperature at the surface is about 6000° C. For comparison, the temperature of molten iron is about 1200° C. Rays from the sun pass out into cold space in all directions from the sun's surface. Some strike the moon, and heat and

Matter is necessary to the production of heat

FIG. 188. Although the Earth receives only an Extremely Small Fraction of the Total Amount of Radiation from the Sun, Enough is received to serve All our Purposes

light its surface. Some rays strike the planets; we see the planets by the light that is reflected from their surface. Some strike our own earth, to furnish heat and light. Remember, however, that if viewed from the sun the earth would be seen as a tiny object, much less easy to see than the planet Venus as we see it from the earth. Thus the earth receives only a small fraction of the total amount of radiation. Yet it is enough to serve all our purposes. Some idea of this may be gained from Fig. 188.

So you may decide that the sun is indeed an enormous source of energy. Yet it is not the only source of energy in the universe. All the bright stars are like the sun in that they too are radiating energy into space. The temperature on the surface of some stars is greater than the temperature on the surface of the sun; the temperature of other stars is less than that of the sun. This radiation, however, has little effect upon the earth, for the distance from the earth to the nearest star is about two hundred and fifty thousand times the distance from the earth to the sun. Others are much farther away. Nevertheless it is interesting to know that vast space is penetrated throughout with radiations coming from huge bodies which appear to us at night as mere points of light. The amount of energy radiated into space from the sun and all the stars, when measured in the units in common use (foot-pounds), is so large that it seems beyond our understanding.

The sun is an enormous source of energy

A further consideration of these facts raises some very interesting questions. There is evidence to show that energy is not destroyed on earth, although it may be changed from one form to another. Is this also true throughout distant space? If so, what becomes of the radiant energy streaming through this space? There is at the present time no answer to this question, for no one definitely knows.

Now let us return to a consideration of what happens to this solar radiation when it strikes the earth. As you know, it is changed into other forms, its most obvious form being heat.

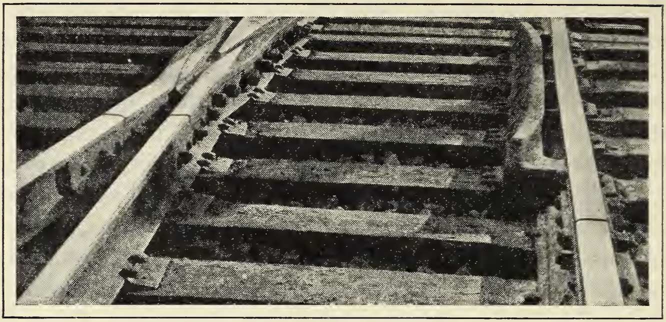
Let us trace the energy cycle in the case of water. Notice the manner in which water is changed as it moves in the cycle. These changes in the water are evidences of energy changes. Solar radiation causes evaporation. Energy is transferred from the rays to the molecules of water. As the molecules move faster, the water becomes warmer.

Molecules continually pass into the air by the process of evaporation. The faster they move, that is, the more energy they possess, the more rapidly they pass into the air. In the air the water molecules may lose some of their energy, condense, form drops, and fall as rain. It is easy to see that the kinetic energy of the falling raindrops is energy that came from the sun. As the water flows from higher to lower levels, it may be made to turn water wheels. In this way the energy from the sun is changed into mechanical energy. The mechanical energy of the wheels may be used to run a dynamo, and thus the energy from the sun may be changed into electrical energy. The electrical energy may possibly be used to run a motor. Energy from water power is energy from the sun.

These changes are not the only ones which may be traced to the sun. Energy from the sun causes chemical changes in the green leaves of plants. Molecules of carbon dioxide and water are changed to molecules of sugar and oxygen. The sugar may be changed into other forms of food, or it may be changed into plant fiber, such as wood. In the end the foods may furnish energy to living cells, and wood may be burned for fuel. The energy in food and in wood is energy that came from the rays of the sun. Coal and oil have been formed from plants and animals. They furnish the basis of our Power Age. So you see that even those substances which help to make our civilization what it is really have their origin in the sun.

C. What is the Nature of Heat?

We have already said that heat is a property of matter and that accordingly there cannot be heat unless there is matter. Let us develop this idea a little further. The molecules of all forms of matter are in continuous motion. All molecules therefore have the capacity to exert a force and to do work. The speed with which the molecules move is



N. Y. C. R. R.

Fig. 189. In Laying Steel Railroad Rails Provision must be made for Expansion

Do you see the expansion gaps?

determined by the amount of energy they contain. The energy of moving molecules is heat. Radiant energy seems to exert a push against molecules. This causes them to move faster. At the same time the moving molecules radiate energy. If a substance is hotter than the matter that is around it, the substance loses energy faster than it gains energy. A red-hot poker held in the sun's rays receives some energy from the sun. But since the poker is much hotter than the air about it, the poker radiates energy faster than it receives it and consequently gets cooler.

Heat may be explained in terms of the molecular theory

As a substance is heated, the molecules acquire energy and move faster. Therefore the substance expands. The faster the molecules move the more space is required for the movement. Solids, liquids, and gases expand when heated. In construction work, like laying steel rails, building bridges, and laying paving blocks, provision must be made for the expansion and contraction that accompanies heating and cooling. Look at Figs. 189 and 190. You know, too, that when a stoppered test tube is

heated the stopper of the tube will be driven out by the force of expansion of the air within the tube.

Let us look a little more closely at these properties of expansion. In this study let us use a gas. All gases show a strikingly uniform behavior when heated. This uniformity may be seen in the fact that all gases expand about equal amounts when equally heated. If the gases are confined, as, for example, in a tightly stoppered flask, the pressure of the gases increases in equal amounts when the gases are equally heated. The increases in volume and in pressure may of course be measured.

Fig. 190. Expansion caused by Heat may under Certain Conditions do Great Damage

This broken and twisted metal was once a boiler

Many experiments with gases have shown that a liter of gas, measured at a temperature of 0° C., when heated 1° C. expands $\frac{1}{273}$ liter when the pressure on the gas remains the same. At the higher temperature the molecules have more energy. Consequently they move faster and crowd each other farther apart. If the gas is confined in a flask so that the volume cannot increase, the pressure of the molecules against the walls of the flask increases by $\frac{1}{273}$. If the temperature of the gas is raised 2° C., the volume will expand $\frac{2}{273}$ liter, the total volume becoming $\frac{275}{273}$ liters. If the gas is confined, the pressure increases by $\frac{2}{273}$. This increase in volume by expansion, or increase in pressure if the gas

The expansion and contraction of gases is uniform

T

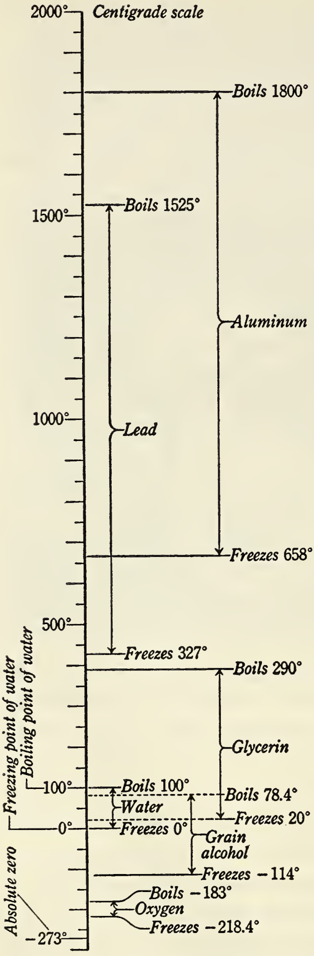


Fig. 191. Temperature determines the States of Matter. Everything would be frozen Solid at the Temperature of Absolute Zero

The boiling point and the freezing point differ in different materials

is confined so that it cannot expand, goes on uniformly as the gas is heated. If the temperature is raised from 0° C. to 273° C. and the gas is allowed to expand without changing the pressure on it, the volume will be just twice as great as at 0° C. If the gas is confined so that it cannot expand, the pressure of the gas at 273° C. is just twice as great as at 0° C.

This fraction $\frac{1}{273}$ applies only when you consider the original volume of the gas as at 0° C. At any other temperature the ratio would be expressed by some other fraction. As a gas is cooled, the volume decreases, or grows less; or if the volume is kept the same, the pressure decreases. The ratio of decrease is the same as the ratio of increase, except, of course, that it is in the opposite direction. Thus if a liter of gas at 0° C. is cooled 1° C., the volume of gas decreases $\frac{1}{273}$ liter. Similarly if the gas is confined, the pressure of the same volume of gas decreases $\frac{1}{273}$ when the temperature decreases 1° C. At the lower temperature the molecules move more slowly and consequently exert less pressure.

If the temperature were reduced to − 273° C., the gas pressure would become zero. In other words, at this temperature the molecules would have no energy, or heat. A temperature of − 273° C. is a temperature of absolute cold. Scientists refer to this temperature as absolute zero.

Most common gases change to liquid at temperatures considerably above absolute zero. Oxygen becomes a liquid at − 183° C., which is 90° C. above absolute zero. Hydrogen becomes a liquid at − 253° C., or 20° C. above absolute zero. Helium changes to liquid at − 268° C., which is but 5° C. above absolute zero. The temperature of absolute cold (− 273° C.) has never been reached, but it has been very nearly reached. The lowest temperature ever recorded is − 272.18° C., less than one degree above the temperature of absolute cold.

The experiments with gases show the relationship between temperature and the energy of moving molecules. Most substances will change through the three states of matter as they are heated or cooled. Water freezes at 0° C. and boils at 100° C. Oxygen freezes at − 218.4° C. and boils at − 183° C. Notice that ice is a hundred and eighty-three degrees hotter than boiling oxygen. Lead freezes (becomes solid) at 327° C. and boils at 1525° C. Thus you see that the energy of the molecules determines the state of matter. As you can see from Fig. 191, the boiling point and the freezing point differ with different materials. All the chemical elements on the surface of the sun (temperature 6000° C.) are in the gaseous state; in other words, they are gases.

Temperature determines the states of matter

D. What is the Relation between Heat and Mechanical Energy?

Have you ever noticed what happens as you hammer a nail on an iron block? The nail gets hot. Have you ever noticed what happens to the bit of a drill which you have

used to bore a hole in hard wood or iron? The bit gets hot. Rub your coat sleeve vigorously for a few minutes. Is there any evidence of heat? Perhaps you have started a fire sometime by the primitive method of rubbing sticks together. All these simple experiences indicate that mechanical energy, that is, the energy of a moving object, may be changed into heat. Consider a hot box on the axle of a railway car or burning brakes on an automobile. In these instances what happened to the moving parts, and why?

Mechanical energy may be changed into heat, and heat into mechanical energy

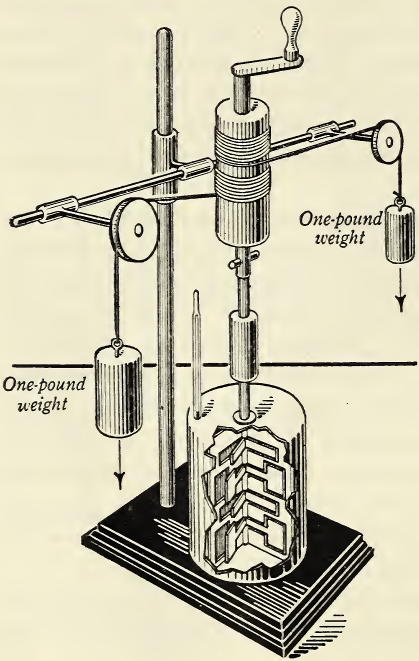


FIG. 192. There is a Relationship between Heat and Mechanical Energy

This diagram shows the apparatus used by an early experimenter

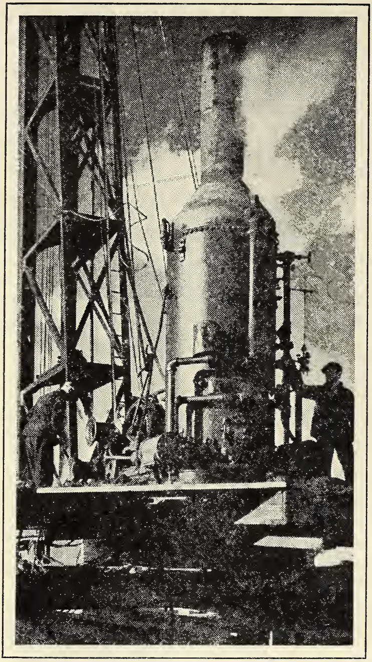
Many experiments have been carried out to find the relation between mechanical energy and heat. The experiments themselves are difficult, but the principle may be understood from a reference to the apparatus and method used by one of the early investigators. Fig. 192 shows a cross section of the apparatus he used. Suppose the weights on the ropes total 2 pounds, and suppose the distance of fall in each case is 1 foot. In the higher position the weights may be said to have 2 foot-pounds of

potential energy. As the weights move through one foot, they do 2 foot-pounds of work, turning the shaft to which the paddles are attached. The force due to pull of gravity on the weights is just sufficient to cause the shaft to turn. Energy of course is expended to stir the water. Now wind up the rope again and bring the weights to the top. Let them fall again. Continue the process. After a time it may be observed that the water is warmer. Suppose that there are 500 grams of water (about a pint) in the can. Careful experiments show that about 1550 foot-pounds of work, done by the weights in moving through one foot, will cause the temperature of the water to rise 1° C.

Let us state the results in another way. You may remember from previous work in science a unit of measurement called the gram-calorie. This was defined as the amount of heat needed to raise the temperature of 1 gram of water 1° C. We can say, then, that 1550 foot-pounds were expended to produce 500 gram-calories of heat. In other words, 1550 foot-pounds of mechanical work are equivalent to 500 gram-calories, or 3.1 foot-pounds are equivalent to 1 gram-calorie. Other experiments have brought similar results, showing that the energy of 1 gram-calorie is sufficient to do 3.1 foot-pounds of work.

The relationship between mechanical energy and heat may be measured

Here, then, are two units (the foot-pound and the gram-calorie) in which we may express the potential energy of materials. You may find the relation between heat and mechanical energy expressed in other terms than these, however. Another unit often used is the British thermal unit (B.T.U.). This unit is the amount of heat required to raise the temperature of 1 pound of water 1° F. By the same experiment described above you may show that 778 foot-pounds are equivalent to 1 B.T.U. Notice that the B.T.U. is much larger than the gram-calorie. The ratio between these two units is $\frac{1}{252}$; that is, one B.T.U. is equal to 252 gram-calories.



Ewing Galloway

FIG. 193. Many Mechanical Devices are Wasteful in their Use of Energy

Why is this statement true of a steam engine, such as the one shown?

You may see now how the energy values of foods and fuels are figured. Careful experiments have shown that the energy released from burning 1 pound of coal is equal to about 3,000,000 gram-calories. The potential energy in 1 pound of coal is therefore sufficient to do about 9,300,000 foot-pounds of work.

When you consider such amounts of potential energy and the fact that steam engines use coal as fuel, you cannot help but come to the conclusion that a steam engine, as shown in Fig. 193, seems very inefficient as a means for changing heat energy into mechanical energy. Let us see if we can support this statement. Remember that the potential energy of fuels is released as the fuels are burned. Suppose all the energy released as heat could be changed into mechanical energy. Each gram-calorie then would be sufficient to do 3.1 foot-pounds of work. But in the best stationary engines only about one fifth of the energy from the fuels may be used to do useful work. In a railroad locomotive only about one twentieth of the energy in the fuel is really used to drive the train.

Many mechanical devices are wasteful in their use of energy

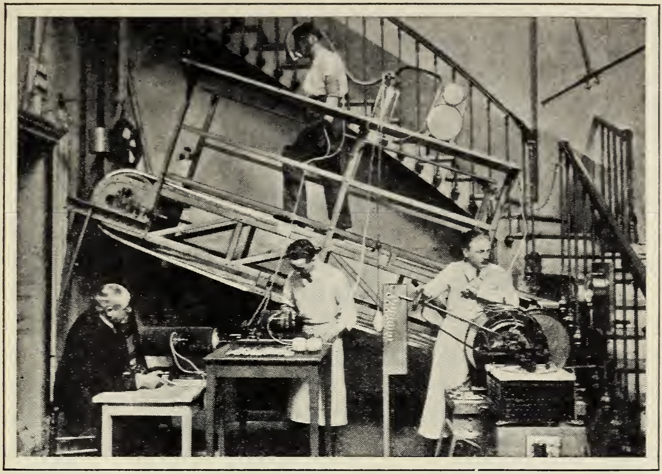


FIG. 194. The Amount of Energy derived from Foods may be Measured

Can you explain the things you see in this picture?

An engine such as is used for pumping water may use coal at the rate of about 1 pound a minute. Suppose that one fifth of the energy produced is converted into useful work. How many horsepower are developed? Since the energy in 1 pound of coal is equivalent to 9,300,000 foot-pounds, the amount changed into useful work is 1,860,000 foot-pounds ($\frac{1}{5} \times 9{,}300{,}000 = 1{,}860{,}000$). One pound of coal per minute in this engine will produce about 56 horsepower ($1{,}860{,}000 \div 33{,}000 = 56.4$).

The potential energy of food may be converted into kinetic energy by burning the food, just as fuels are burned. Experiments show that one large slice of bread furnishes about 100,000 gram-calories. When the bread is oxidized in the cells of the body, the same amount of energy is released. Some of it is used by the muscles, some is used to maintain the temperature of the body, and some serves other purposes. An apparatus like the one shown in Fig. 194 may be used to measure the amount of energy derived from

foods. The amount of oxygen the man uses tells the amount of food he uses. The machine registers the amount of work done as the man walks. Careful experiments show that 28 per cent of the energy in food may be converted into muscular energy. Therefore the large slice of bread may furnish 28,000 gram-calories ($0.28 \times 100{,}000 = 28{,}000$) of muscular energy. Since 1 gram-calorie is equivalent to 3.1 foot-pounds, the energy supplied to the muscles by the slice of bread is 86,800 foot-pounds ($3.1 \times 28{,}000 = 86{,}800$).

From this you may see where your energy comes from. If you weigh 124 pounds, the energy from one slice of bread would be sufficient to carry you up a hill 700 feet high ($700 \times 124 = 86{,}800$). Of course you know that you need three meals a day whether you climb the hill or not. In climbing you make many motions besides those that raise the body to the higher level. In practice, then, you would find that the single slice of bread would be insufficient.

E. How has the Use of Energy influenced the Culture of People?

Among the Seven Wonders of the Ancient World are some great engineering achievements, including the pyramids of Egypt, the temple of Diana, and the tomb of Mausolus (shown in Fig. 195). Other great engineering developments include the Great Wall of China, the Colosseum at Rome, and the mosque of Saint Sophia (also in Fig. 195). As we observe men today, completing as they do great engineering developments in relatively short periods of time, we wonder how these older wonders could have been built at a time when engineers knew nothing about the use of energy from oil and coal.

The largest of the pyramids (Cheops) is built of about 135,000,000 cubic feet of stone. The stone is in the form of blocks, each of about 40 cubic feet. Each block weighs about 6000 pounds. More than three million of these

Fig. 195. Some Great Engineering Feats were achieved long before the Days of the Age of Power

The pyramids of Egypt, the tomb of Mausolus, and the temple of Diana are included among the Seven Wonders of the Ancient World. The other structures shown here are the Great Wall of China, the Colosseum in Rome, and the mosque of Saint Sophia in Constantinople

blocks were used. It was necessary to convey them across the Nile River and across about eight miles of level country to the position where they were finally set in place.

Ancient civilizations depended upon energy from muscular effort

Such a piece of engineering was possible only because kings and emperors were able to control large numbers of men. The manner in which they were controlled and the conditions under which they worked seem shocking to us today. A quotation from ancient records tells how the workers were often driven until they dropped dead from exhaustion.

Levers, rollers, pulleys, ropes, and the inclined plane were used in moving the stone. No records are left that fully describe this feat of engineering. It is generally believed that these ancient Egyptians built an enormous inclined plane (in some such fashion as that shown in Fig. 196), up which the blocks were pushed or pulled into position. The plane was several hundred feet long, and in order to get the last blocks into position it was necessary that it be 482 feet high.

The slaves that moved the stones were able to work at the rate of about one seventh of a horsepower. It is believed that the men worked in relays, about a hundred thousand at a time, and that twenty years were required to complete the work.

If engineers of today were to build a structure like the pyramids, energy from fuels would be used in place of the energy of human slaves. The scene might look like that in Fig. 197. These modern workers might follow the example of the Egyptian engineers and build an inclined plane up which the stone blocks would be raised. The plane would be built so that trucks could go up and down it. Trucks with 150-horsepower engines would be used, instead of men with $\frac{1}{7}$ horsepower, for moving the blocks up the plane. Each truck would probably carry two blocks

Modern civilization depends upon man's control of energy resources

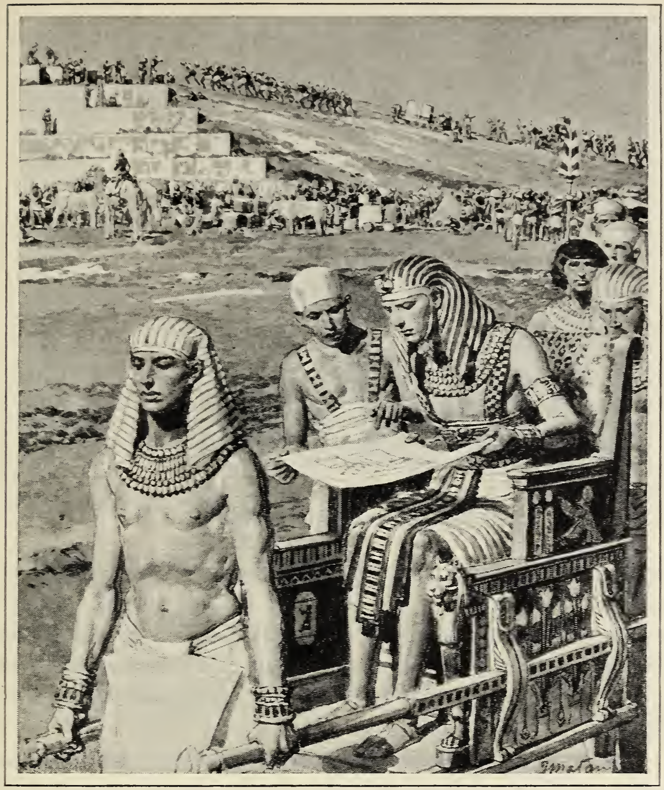
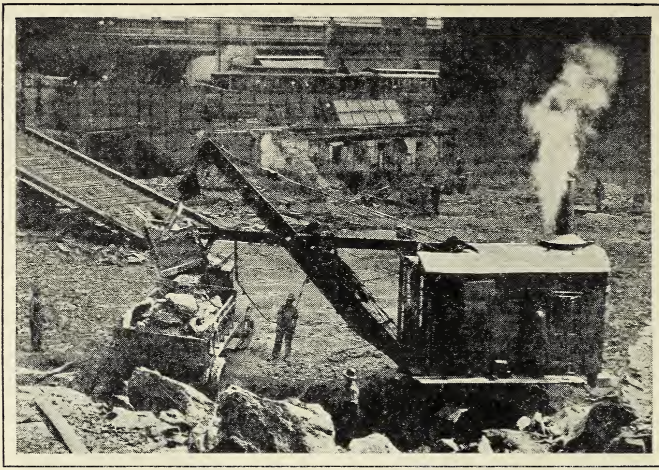


FIG. 196. The Building of the Pyramids was Possible only because Kings and Emperors were able to control Large Numbers of Men[1]

and would move up the plane, probably, at a speed of 15 miles per hour. The blocks would be swung into place by large derricks operated by steam power. Working on a twenty-four-hour shift, one truck might make twenty-four trips up the plane in one day. If a hundred trucks were kept working continually at this rate, the work would

[1] From Pahlow's *Man's Great Adventure.* Ginn and Company, publishers, 1932.



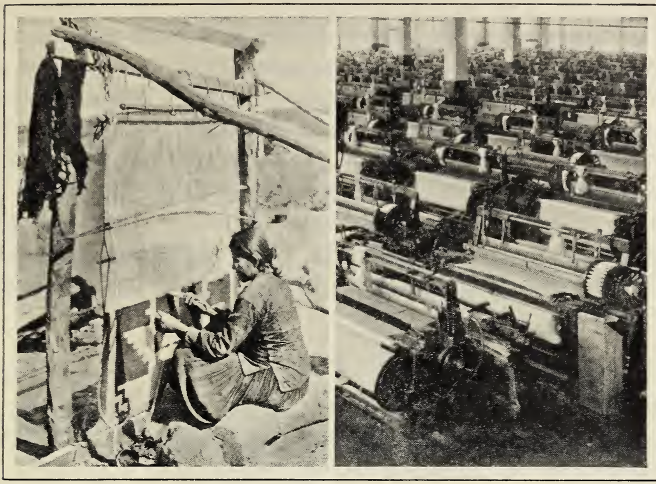
Ewing Galloway

Fig. 197. Modern Building depends upon the Energy from Fuel rather than from Human Muscles

be done in less than two years. A few hundred men, then, working with little or no physical strain, would be used in place of a hundred thousand slaves. In a work of this kind today energy from gasoline and coal is used to do the work. Certainly man's control of energy has changed his ways of building.

Learning to control energy has greatly changed our methods of transportation too. Only a few hundred years ago horses were used as the most rapid means of transportation. A horse is supposed to work at the rate of 1 horsepower. Today there are railroad locomotives that work at the rate of 5000 horsepower. For transportation over the highways we have substituted automobiles of a hundred or more horsepower for the horse of 1 horsepower. Engines of 400 horsepower and more are used for transportation through the air.

Our methods of manufacturing have changed tremendously as man has learned to control energy. Only a little



Keystone Ewing Galloway

FIG. 198. Our Methods of Manufacturing have changed tremendously as Man has learned to control Energy

Contrast weaving by hand with weaving by the machine process

Control of energy has transformed man's ways of working

while ago most of the clothing was manufactured in the home by a slow and tiresome process. Today energy from coal runs the machines that do the weaving. The hand method and the factory method are shown in Fig. 198. In the iron and steel mills great loads of iron ore are changed into iron. This is a chemical process, and the energy for the chemical change comes from coal. The iron is manufactured into heavy machinery, and this in turn is handled by machines driven by energy secured from coal. Only a few men are required to control the machines.

Some figures furnish a comparison of the rate at which energy is used today with the rate at which it was used only a few years ago. In 1860, as you have seen, very little coal was used. In 1890 about 150,000,000 tons were used in the United States. In 1929 more than 500,000,000 tons

were used. (Look again at Fig. 140, p. 257.) The production of petroleum in the United States increased from about 64,000,000 barrels (1 barrel equals 42 gallons) in 1900 to more than 1,000,000,000 barrels in 1929. The energy in 1 pound of coal will do about 9,300,000 foot-pounds of work, and the energy in 1 pound of petroleum will do somewhat more. An increase of 350,000,000 tons of coal in forty years and an increase of nearly 1,000,000,000 barrels of petroleum in thirty years show the enormous increase that there has been in the rate at which energy is used.

Energy is characterized as potential and kinetic. Energy cannot be created by machinery; most of it comes from the sun. Energy may be measured and the efficiency of machinery in using energy determined. Man's control of energy has had an important effect upon his culture.

Can You Answer these Questions?

1. How should you define *energy*?

2. What are some of the relationships of force, work, and energy?

3. How does potential energy differ from kinetic energy? How may one be changed to the other? Give several illustrations.

4. Why does it seem unreasonable to suppose that a real perpetual-motion machine will ever be perfected?

5. What evidence is there to support the idea that at some time solar radiation may be a direct source of energy for industry?

6. Is it correct to say that the sun's rays are heat? Why?

7. What other sources of energy besides the sun are there in the universe?

8. How may heat be explained in terms of the molecular theory?

9. What is meant by the statement that the expansion and contraction of gases are uniform?

10. What evidence is there to support the statement that temperature determines the states of matter?

11. What is the relation between heat and mechanical energy?

12. What is the B. T. U.? the gram-calorie?

13. How is the potential energy of food converted into kinetic energy?

14. What are some of the chief differences between the forms of energy used in ancient civilizations and in our own?

Questions for Discussion

1. What changes in forms of energy take place as a meteorite plunges downward through the atmosphere to the earth?

2. At the rate we are using energy is there not danger that we may soon use all we have?

3. Why do you think that solar engines are not yet in common use?

4. Why is a steam engine an inefficient machine for changing energy from one form to another?

5. What should you call the seven wonders of the modern world? Support your answer.

6. Is it possible that energy may at some time be as easily obtained for all purposes as water and air are now?

Here are Some Things You May Want to Do

1. Demonstrate how kinetic energy may be changed into heat.

2. Illustrate by a blackboard talk the changes from potential to kinetic energy, and the reverse, in some common energy cycle.

3. Prepare a short talk on "Perpetual-Motion Machines."

4. See if a radiometer will work under a strong electric light as well as under sunshine. Explain your findings.

5. Ask your science teacher to help you to set up apparatus which will show that different metals expand in varying degree.

Chapter XVIII · How does an Engine change the Potential Energy of Fuel into Kinetic Energy?

The development of railroads paralleled the expansion of the United States

What do you know about early life on the Western frontier of our country? Have you ever read anything about it? You should, for it is one of the thrilling chapters dealing with the development of this country. A hundred years ago the Western Plains of the United States were largely undeveloped. Small settlements had been established, but the main centers of population were to be found in the East and, as a result of the gold rush (1849), in the Far West. At first, communication between these points was maintained by stagecoaches which traveled regular routes, taking some three weeks for the long journey between St. Louis and San Francisco. You can imagine the dangers and hardships of such a trip. At the same time there were the pony-express riders, carrying the mail over a route of some two thousand miles between St. Joseph, Missouri, and San Francisco in about ten days. Changing horses frequently and riding at breakneck speed, these daring men helped to make American history.

As late as 1850 there were only about nine thousand miles of railroad in the whole United States. Check this with the railroad mileage of today, and you will find part of the answer to the question why the United States has developed so rapidly. Today, as you know, you can board a train in almost any part of the country and travel with speed and comfort west, east, north, and south.

What made this rapid development of land transportation possible? Briefly the answer may be found in man's control over his energy resources. At greater length the story includes the development of engines. It is this longer story that will be told in this chapter.

A. How does a Steam Engine change the Energy of Fuels?

A simple toy engine serves very well to illustrate how the more complex steam engine works. Notice the essential parts of it shown in Fig. 199. Find the fire box, boiler, steam chest, slide valve, cylinder, piston, flywheel, and exhaust.

In this toy engine fuel may be gas or alcohol. As the fuel burns, its potential energy becomes the kinetic energy of moving molecules of hot steam. Energy from the fuel is transferred to molecules of water in the boiler. After a time the water boils. The pressure exerted by the moving molecules is now greater than the pressure of the atmosphere. Steam passes from the boiler to the steam chest and then through the slide valve into the cylinder. Within the cylinder the steam pressure acts as a force against the piston. The piston is pushed along by this force toward one

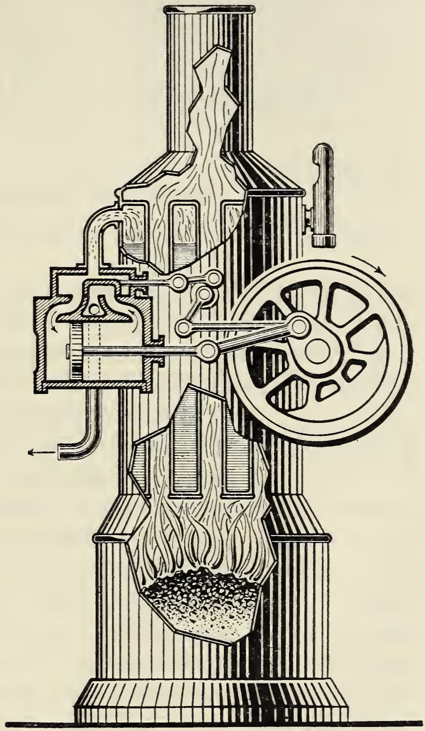


Fig. 199. A Simple Toy Engine may be used to demonstrate how a More Complex Engine Works

Can you locate the various parts referred to in the text?

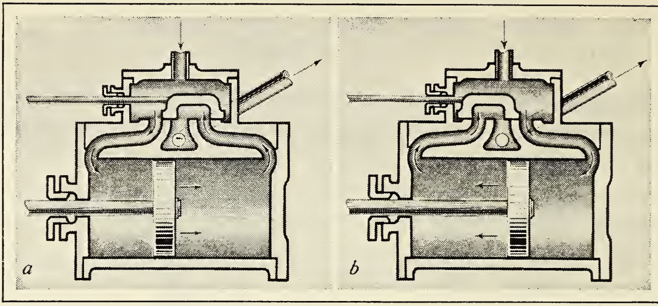


Fig. 200. As Steam enters the Cylinder of a Steam Engine, it forces the Piston to move Back and Forth

How does the slide valve cause the direction of the piston to change?

end of the cylinder. The piston rod is attached to the fly wheel. When the piston moves, it causes the flywheel to turn.

Kinetic energy of steam works against the piston

But why does the piston move back and forth? Study the slide valve shown in Fig. 200. You will find an opening into each end of the cylinder; notice that the piston slides back and forth between these two openings. In Fig. 200, *a*, steam pressure is driving the piston from the left toward the right. As soon as it reaches the right end of the cylinder, the piston starts back toward the left. How does this happen? Notice the slide valve. It is joined with a connecting rod to the eccentric, and this is attached to the shaft which turns the flywheel. The motions are timed in such a manner that the slide valve is pulled toward the left before the piston reaches its position farthest toward the right. This closes the valve between the steam chest and the left-hand side of the cylinder (Fig. 200, *b*) and opens the valve between the steam chest and the right-hand side of the cylinder. Pressure from the steam now drives the piston back toward the left. The used steam is forced out through the exhaust. By examining a toy steam engine, you may learn how an engine works.

A real engine, such as you saw in Fig. 193, may be used for lifting or for other work in a factory. Suppose an engine burns coal at the rate of 12 pounds an hour. This is at the rate of $\frac{1}{5}$ pound each minute. One pound of coal, you may remember, is equivalent to about 9,300,000 foot-pounds. For convenience let us say it is 10,000,000 foot-pounds. One-fifth pound is equivalent to 2,000,000 foot-pounds. Work at the rate of 2,000,000 foot-pounds each minute is at the rate of about 60 horsepower ($2{,}000{,}000 \div 33{,}000 = 60.6$). In an engine of this kind about 20 per cent of the energy from the fuel may be converted into useful work. Therefore an engine burning coal at this rate will really develop power at the rate of about 12 horsepower.

B. How is Energy used in a Railroad Locomotive?

One of the greatest achievements in the use of energy from coal is found in the modern locomotive. In the engine yards of one of the great railroad companies you can find several of the powerful iron horses that pull heavy trains. Fig. 201 shows a number of them. An engine just in from a run may be undergoing inspection and overhauling to make it ready to go out again. Another engine may be ready to pull a fast and heavy train on a long run. All the moving parts have been carefully inspected by men trained for this work. This inspection is extremely important. The engine may pull a train of ten or more cars, carrying about a hundred and fifty passengers. The total cost of the train will be about a million dollars. Every precaution must be taken to prevent a wreck.

A locomotive is an enormous machine

The fireman may be in the cab working rather leisurely at getting up steam. Coal is fed to the fire box by an automatic stoker, so his work is not heavy. If you could engage him in conversation, he might tell you that the engine weighs more than 300 tons and that it is about 90 feet long. When starting a trip

N. Y. C. R. R.

Fig. 201. One of the Greatest Achievements in the Use of Energy from Coal is found in the Modern Locomotive

it carries 28 tons of coal and about 14,000 gallons of water. If you could look into the fire box, you would see a brilliant hot fire distributed over a grate area of about 80 square feet. While pulling a heavy train at high speed this engine will burn about 3 tons of coal an hour. Its load of 28 tons of coal therefore is enough for a nine-hour run.

Water is changed to steam in the boiler

These figures seem impressive and interesting, but you want most to know how the engine works. In other words, how is the energy from coal transferred from the fire in the fire box to the wheels that run on the track? Looking through the fire box, you may see toward the front end the openings of the boiler tubes (Fig. 202). It is through these boiler tubes that the hot gases pass on their way to the smokestack. Their path is shown in Fig. 203. The boiler in which the water is changed to steam is built around these openings. This arrangement exposes a large amount of boiler surface to the heat.

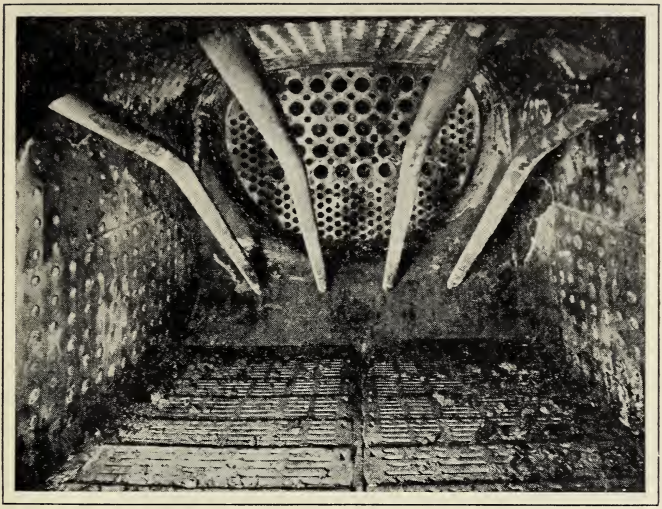


FIG. 202. The Hot Gases from the Fire Box of a Locomotive pass through the Boiler Tubes which you see at the Rear and heat the Water which surrounds them, changing it to Steam

Trace the course of these gases in Fig. 203

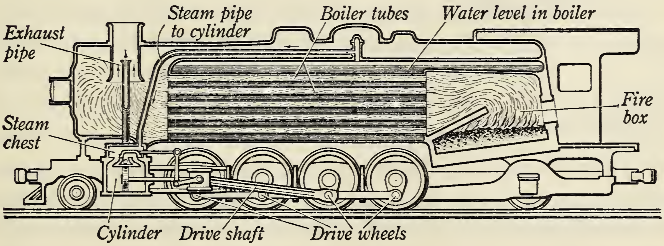
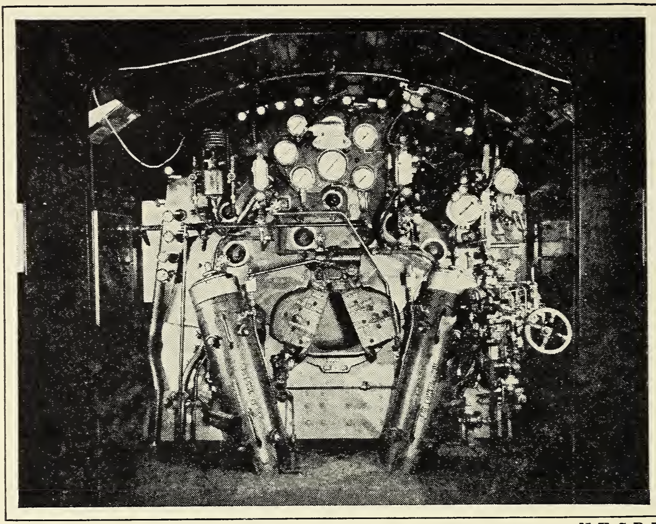


FIG. 203. A Steam Locomotive is a Complex Machine which changes the Potential Energy of Coal or Oil into Kinetic Energy

Can you trace the path of this energy from the fire box to the drive wheels?



N. Y. C. R. R.

Fig. 204. The Engineer of a Modern Steam Locomotive must be Familiar with All these Instruments

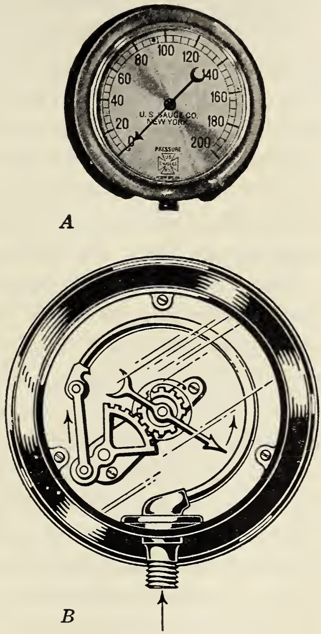
Which do you think is the easier to run, the train that has this cab or the one with the cab shown in Fig. 217?

The steam engine is an external-combustion engine

Inside the cab, as shown in Fig. 204, are instruments by means of which the engine is controlled. It certainly looks complex, doesn't it? Yet the engineer knows exactly what each instrument is used for. Let us describe some of them for you. There is a stoker engine, which is really an engine within an engine. It runs the automatic stokers which feed coal to the fire box. The fireman, using a shovel, could hardly feed coal to the fire box fast enough to keep up steam while this engine is pulling a heavy train. There are steam-pressure gauges. In addition to pulling the train and stoking the coal the engine must supply heat and hot water to the cars. One gauge therefore indicates the pressure in the system which supplies steam heat to the cars. Another

gauge shows the pressure in the stoker engine. The large gauge near the center indicates the pressure in the main boiler. The figures on this dial run to something over 225, for many of the big engines used in passenger service carry a boiler pressure of about 225 pounds. On the side of the cab that is next to the engineer's seat (on the right) are the levers by means of which the engineer controls the throttle, the air brakes, and other things used to keep the engine running properly and the passengers comfortable in the coaches behind him.

The pressure gauge is the center of interest when the engineer is getting ready for the run. If it is not time for the engine to go out, the gauge may read considerably less than 225. As the time to start approaches, the fire is hastened, and the pointer on the dial moves slowly around toward 225. You understand, of course, that the pressure cannot go higher and higher. If it did, the boiler would finally burst. As a protection, then, all engines are equipped with a safety valve. Even your toy engine has one. If the pressure goes too high, the valve opens automatically. Then there is a roar of steam rushing through it and continuing until the pressure is lowered to the proper point. A common form of pressure gauge is shown in Fig. 205.



A

B

FIG. 205. Pressure Gauges, such as the One shown here, register Steam and Air Pressure in the Boiler of the Locomotive

A, the gauge as it looks to the engineer; *B*, the mechanism of the gauge

How is a pressure gauge constructed? The essential feature of it is a hollow metal spring attached to the boiler in such a way that the pressure of steam from the boiler is applied inside the hollow coil. The closed end of the spring is attached to the pointer by means of a lever and cogs. As pressure increases inside the spring, the coil straightens. The closed end of the spring in the picture would move toward the right as pressure increases inside it. This movement would cause the pointer to move toward the larger numbers on the dial. As the pressure decreases, the end of the spring moves back toward its original position. Study Fig. 205, *B*.

A steam gauge records the pressure of the steam in the boiler

Suppose that full steam pressure is up and that the engine is ready to start. The engineer pulls a lever and opens the throttle valve. This valve allows steam to pass from the boiler to the steam chest and into the cylinders. The cylinder of this large engine is similar to the cylinder of the toy engine. There are a steam chest, slide valve, and exhaust. Find them in Fig. 203. In the cylinder the force of the steam pressure is against the piston, and this pressure causes the piston to move. The piston is joined by a system of levers to the drive wheels; and as the piston moves, it causes the wheels to turn. Steam leaves the exhaust and escapes through the smokestack. The puff of the engine is really the noise of escaping steam. The "white smoke" from the smokestack is not smoke at all but steam from the exhaust.

If you stand beside the engine as it begins to move, you may observe certain moving parts. The piston rod moves back and forth in the cylinder. As it moves, the force of the molecules of hot steam is carried to the wheels. In one type of engine these drive wheels are about 20 feet in circumference. One complete turn of the wheel, then, carries the engine forward on the track a distance of 20 feet. The length of the piston in this same engine is 28 inches. While

the piston makes one back-and-forth motion, the drive wheels turn around once.

Let us look at this piston a little more closely. The pressure of the steam on the piston is not uniform throughout the entire stroke. As the piston moves from one end of the cylinder toward the other, some of the force is used to drive the steam from the last stroke out through the valves. The steam is cut off by the slide valve after the piston has moved about one third the length of the cylinder, and the force of expansion of the steam drives it the remainder of the distance. As the piston moves, the pressure diminishes until at the end of the stroke the pressure is very low. In other words, the strokes begin with a high pressure and end with a low pressure. Obviously, in order to figure the force exerted and the work done by the steam, the average pressure against the piston during a stroke must be determined.

Steam pressure drives the piston

The engine mechanic has an instrument called an indicator, with which he may determine the average pressure. The value varies with different engines, and in the same engine it varies at different speeds. In big engines in common use, when the boiler pressure is 225 pounds the average pressure against the piston is about 112 pounds per square inch when the engine is running at 60 miles an hour.

Now let us see if we can figure the average pulling force and the horsepower of one of these locomotives. In the common type of locomotive used on express trains there are two cylinders, one on each side. Both are just alike. The two cylinders are each 25 inches in diameter and 28 inches long. When the throttle is open and the engine running, the pressure of 112 pounds per square inch pushes against the piston. The area of the piston is about 490 square inches. The total pressure on each piston in this case, then, is about 54,880 pounds ($112 \times 490 = 54,880$). The force of the two pistons is 109,760 pounds ($2 \times 54,880 = 109,760$).

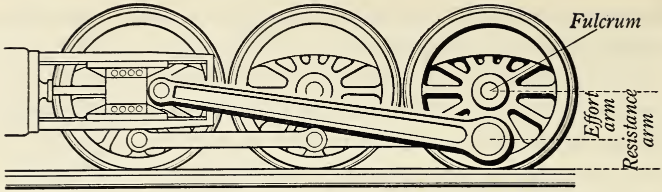


FIG. 206. The Drive Wheel of a Locomotive acts as a Lever

Can you explain how?

This pulling force is carried to the drive wheels by means of the connecting rod. The wheel acts as a lever. The fulcrum of this lever is the axle, and the force turning the wheel is applied between the axle and the rim, as shown in Fig. 206. The resistance arm of this lever is the distance from the axle to the rim. The effort arm is the distance from the axle to the point on the spoke at which the force is applied. By applying your previous knowledge of levers to the diagram in Fig. 206 you see that the spoke of the wheel may be considered a lever of the third class. The effort is greater than the resistance, but the distance through which the resistance moves is greater than the distance through which the effort moves. In one type of engine used in passenger service the force applied at the rails when the steam pressure is 225 pounds per square inch is 42,300 pounds.

Force is applied to the wheels through a third-class lever

What is the horsepower of such an engine? Suppose that the engine is running at a speed of 1 mile (5280 feet) a minute. Since the drive wheels are about 20 feet in diameter, they will make 264 complete revolutions in running this distance ($5280 \div 20 = 264$). Figure the total distance which the force acting against the piston moves during one minute. Why is this necessary? Remember that the average force against the piston multiplied by the distance which it moves gives a measure of foot-pounds, which in turn is a measure of the amount of work done. Since 33,000 foot-

The horsepower of a locomotive may be measured

pounds equal a horsepower, the product in foot-pounds must be divided by 33,000 in order to find the total horsepower.

Now let us work out our figures, beginning with foot-pounds. For each revolution of the drive wheel there is one complete stroke (back and forth) of the piston. Since the cylinder of the engine is 28 inches ($2\frac{1}{3}$ feet) long, the piston with each revolution of the drive wheel moves through $4\frac{2}{3}$ feet ($2 \times 2\frac{1}{3} = 4\frac{2}{3}$). In 264 revolutions, then, the piston moves through 1232 feet ($264 \times 4\frac{2}{3} = 1232$). Now consider the average pressure against the piston, which, as you have seen, is a force of 54,880 pounds. To state the part played by this force we may say that there is a force of 54,880 pounds moving in the piston through a distance of 1232 feet a minute. To complete the statement, the work done in one minute by this force is 67,612,160 foot-pounds ($1232 \times 54{,}880 = 67{,}612{,}160$). Since 1 horsepower is 33,000 foot-pounds per minute, the horsepower of each cylinder of this locomotive traveling at the speed of a mile a minute is about 2050 ($67{,}612{,}160 \div 33{,}000 = 2048+$). But there are two cylinders. Therefore the horsepower of the engine is about 4100. The engine on which these figures are based maintained an average of 2482 horsepower (measured at the piston) throughout a run of 140 miles. What happened to the remaining power? You understand, of course, that not all the force is delivered as a pull on the train behind the engine. Some of it is lost by friction of the moving parts. Measured in terms of pull on the drawbar (the coupling between the engine and the train), the horsepower of the engine from which these measurements were taken was only 1834. The power of the locomotives used on heavy passenger trains is commonly within the range of from 3000 to 4000 horsepower.

From the scientific point of view, then, the steam engine is a mechanism by means of which man controls the energy of moving molecules. Power comes from energy released by chemical changes going on as coal burns in the fire box.

Part of the energy from the coal is transferred to the molecules of water which make up the steam that goes to the cylinders. But not nearly all the energy that is in the coal is really used to drive the pistons. The coal is fed into these huge engines at the rate of about 3 tons an hour. This amount of coal burned in one hour furnishes enough energy to develop more than 30,000 horsepower if all of it could be applied as a force against the pistons. As you stand near an engine, you are well aware that not all the energy is delivered to the cylinders. You feel the heat that is radiated to the air from the whole surface of the boiler and the fire box. A great deal of heat passes out with the hot gases that escape through the flues. Another large quantity of heat is carried away in the steam from the exhausts. In the best locomotives only a little more than 6 per cent of the energy in coal is used to drive the engine. Putting it even more simply, when an engine was burning coal fast enough to release 30,000 horsepower, it produced at the drawbar only 1834 horsepower. Study Fig. 207.

The steam engine is a machine of low efficiency

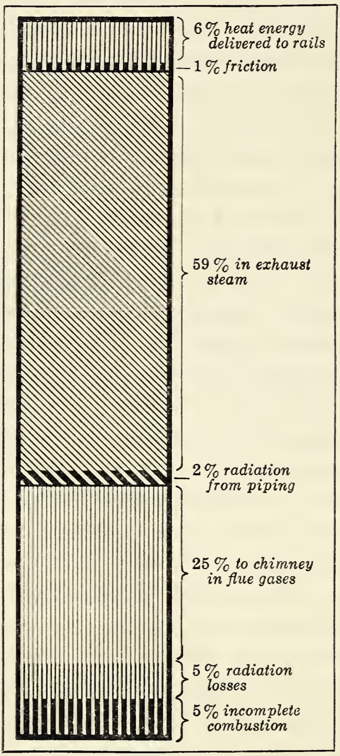


Fig. 207. Even in a Modern Locomotive Much of the Energy from the Fuel is Wasted

What are the main causes of waste? Can they be reduced?

With the steam engine, man has brought enormous

forces under control. As we pointed out at the beginning of this chapter, most of the travel in the United States a hundred years ago was done with teams of two or four horses hitched to stagecoaches. Eight miles per hour was fast travel for these horse-drawn vehicles, and 2 tons was a heavy load. The modern train is pulled by a force equal to the pulling force of two thousand horses, and this force is applied in such a way that a train weighing 1000 tons may be pulled along at a speed of from 60 to 80 miles per hour.

The steam locomotive is a product of the Age of Iron

But even this monster steam locomotive with all its power is not good enough for the demands of today. It is a product of the Age of Iron, and already demands are being made for something better. Automobiles and airplanes are faster. Therefore the locomotive must develop greater speed. But how? More speed requires more power, and more power requires more fuel. In order to carry more fuel the tender must be enlarged, and in order to burn more fuel the fire box must be enlarged. And so the engine gets heavier and heavier.

With the approach of an Age of Aluminum new developments in railroading may be expected to come rapidly. The steam locomotive will probably be replaced by one driven by an internal-combustion engine, which you will find described on page 394 and following. For construction work aluminum may largely replace iron and steel. Some evidences of these changes may already be seen.

The development of the steam engine has had an important effect upon economic development

Besides revolutionizing the ways in which people travel and live, the development of the steam engine has had a tremendous effect upon the economic life of this country. If we should compare the occupations of men before and after the invention of the steam engine, we should find great differences. The development of the railroad made a demand for new products. New occupations and new industries developed in rapid order.

Steel rails were needed for tracks. Hundreds, even thousands, of men went into the mines to dig iron ore. Men were employed at the smelters in which the iron ore was changed to iron. Men were employed in the iron and steel mills which made the iron into rails. Many more men were required to make the roadbeds and lay the rails.

But this was only a small part of the change. It was necessary to manufacture locomotives and cars, and this required ironworkers as well as woodworkers. Finally men were required to operate the trains. Each big development led to the establishment of many other developments. New towns were built along the roads, and many of these developed rapidly into great cities. The great wilderness of the West was opened up for settlement. In 1920 there were two million railroad employees in the United States with total wages of nearly four billion dollars. Several more millions were employed in industries that had been built up as a result of the railroads. While these figures have dropped somewhat in the last few years owing to newer types of transportation, the industries which depend upon the steam locomotive still play an enormously important part in American economic life.

C. How is Energy used in a Gasoline Engine?

The gasoline engine is an internal-combustion engine

The development of the gasoline engine was another great step forward in the control of energy. Soon after the gasoline engine came the automobile, and a little later the airplane. Power for this type of engine comes from an explosion which takes place in the cylinders. To distinguish it from the steam engine it is called an internal-combustion engine. The combustion, that is, the burning, goes on inside the cylinders.

We say that the power for an internal-combustion engine comes from an explosion. What do we mean? An explosion

is a rapid burning and a sudden release of energy. You may be familiar with the explosion of hydrogen that takes place when a match is applied to a mixture of hydrogen and air in a glass bottle or a test tube. A mixture of gasoline vapor and air will explode in the same way. Gasoline is a liquid, but it evaporates rapidly and changes to vapor. In this form it will mix with air and, when ignited, explode.

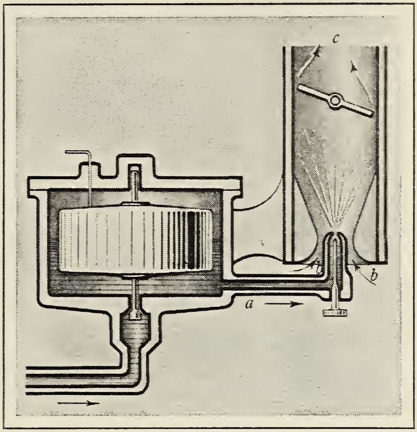


Fig. 208. The Carburetor of an Automobile Engine mixes the Gasoline with the Air

The gasoline, flowing at *a*, is mixed with the air at *b*. The mixture, in the form of vapor, enters the engine cylinder at *c*. The proportions of gas and air may be controlled by the valve in the engine pipe

You may know a good deal about the engines used in automobiles. Gasoline as vapor is drawn into the cylinders through the carburetor, and as it passes through the carburetor the vapor mixes with air as shown in Fig. 208. If the carburetor is correctly adjusted, the mixture of gasoline vapor and air is in proper proportions for the most powerful explosion. For this the mixture that enters the cylinders should contain about sixteen parts of air and one part of gasoline vapor.

Let us look at the cycle of changes in which the energy released by the explosions is made to drive the pistons of an automobile or other gas engine. As a piston moves downward, there is a decreased pressure behind it. Thus outside air pressure forces gasoline vapor and air through the intake valve into the space behind the piston (see Fig. 209, *A*). Just before the piston starts upward again

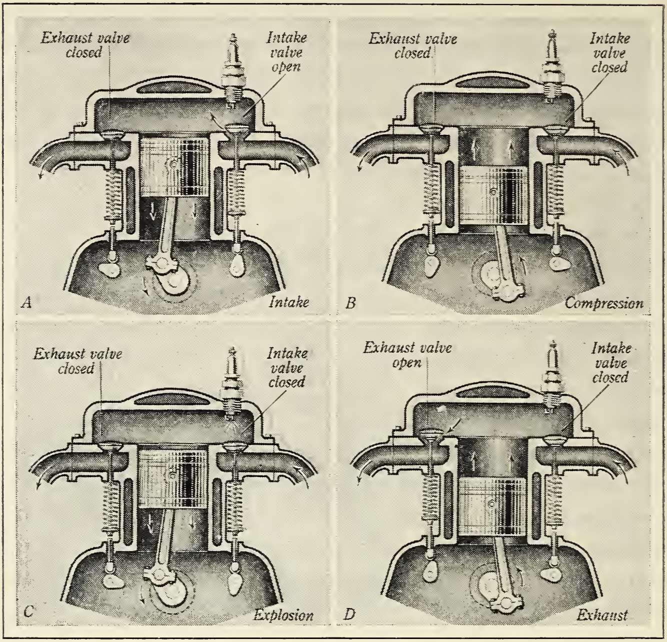


Fig. 209. The Explosions of a Mixture of Gasoline and Air in the Cylinders of an Automobile Engine release the Energy which drives the Car

This diagram explains a four-cycle engine. Do you know of any other type?

The power of a gasoline automobile engine comes from the explosion of a mixture of gasoline vapor and air

the valve closes (as shown in Fig. 209, *B*), so that the mixture of gasoline vapor and air cannot escape. Under these conditions the upstroke of the piston compresses the mixture of explosive gases into a very small space. Just after the piston starts downward again an electric spark crosses the terminals of the spark plug (Fig. 209, *C*), and this causes an explosion in the cylinder. This explosion drives the piston downward with considerable force. As the piston starts upward again (see Fig. 209, *D*) the exhaust valve, which has been closed

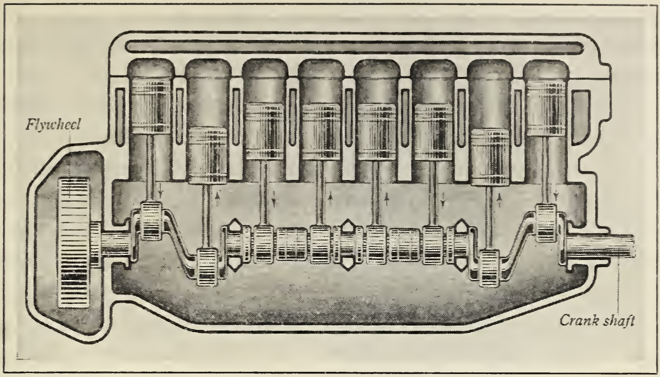


FIG. 210. The Pistons of an Automobile Engine are attached to the Crank Shaft in such a Way that as they move up and down in the Cylinders the Crank Shaft turns Round and Round

up to this instant, opens, and the upstroke forces through the exhaust and out into the air the gases left from the explosion. Now the piston starts downward again, the intake valve opens, and a new supply of the explosive mixture is forced by air pressure into the cylinder. If you study the diagrams carefully, you will see that the piston moves four times the length of the cylinder (twice downward and twice upward) for each explosion. This type of gasoline engine is called a four-stroke, or four-cycle, engine. The four strokes are (1) intake, (2) compression, (3) power, and (4) exhaust. Do you see why these terms are used?

The pistons are attached to the crank shaft in such a way that as they move up and down in the cylinders the crank shaft turns round and round (Fig. 210). The engine is started by turning the crank shaft with the starter. The energy to turn the starter comes from the battery. As the crank shaft turns, gas enters the cylinders. If the ignition, or electric circuit, is on, the gas in the cylinders is fired by the electric spark that jumps across the spark plug. When the engine begins to fire, the starter is released, and the ex-

plosions in the cylinder keep the crank shaft turning. Explosions in the cylinders occur in a regular order, and each explosion acts as a powerful push on the piston.

The first automobiles had one-cylinder engines. Since the crank shaft must turn twice around for each explosion, it was necessary to use a heavy flywheel to keep it turning through the interval between explosions. But with one cylinder the explosions came so far apart that the early automobiles moved with a jerky motion, especially when starting and when moving at slow speed. With engines of two cylinders the time between explosions was divided by two. With the modern engine of eight or more cylinders the explosions come so close together that they can hardly be noticed either by hearing or by feeling. The flywheel of a modern automobile engine of a hundred horsepower weighs about sixty pounds. One of the early one-cylinder cars had a flywheel that weighed three hundred pounds.

The power of a modern automobile may be measured

The force of the explosion of gasoline in a modern gasoline engine gives an average push of about 100 pounds per square inch. The bore (the size of the cavity) of the cylinder of many cars in common use is a small fraction over 3 inches. The area of the piston in these cars therefore is about 7 square inches. The total force against the piston, then, is about 700 pounds. But this explosive force must carry the piston through the four strokes known as intake, compression, explosion, and exhaust, during which the piston moves four times through the length of the cylinder. The average force of 700 pounds working through one length of the cylinder, then, is about equivalent to 175 pounds ($\frac{1}{4}$ of $700 = 175$) moving four times through the cylinder. Thus we may say that the total work done by each explosion is equivalent to a force of about 175 pounds moving four times through the length of the cylinder.

There are two revolutions of the crank shaft for each explosion. The flywheel of the crank shaft rotates three

thousand times per minute while the engine is running at high speed. There are therefore fifteen hundred explosions in each cylinder every minute. If there are eight cylinders, there is a total of twelve thousand explosions per minute. In other words, the force that drives a car along is the total force of twelve thousand explosions per minute, each of which exerts an average push from one explosion to the next of 175 pounds. In these cars the stroke is about $4\frac{1}{2}$ inches. The total distance through which the force of 175 pounds moves in one stroke, then, is 18 inches ($4 \times 4\frac{1}{2} = 18$). With these measurements it is easy to figure the horsepower of this engine. It is necessary to figure the amount of work done in one minute by this force of 175 pounds that is working in each cylinder. Since there are fifteen hundred explosions in each cylinder in one minute, the force moves through 27,000 inches ($18 \times 1500 = 27,000$). The sum of the distances moved by the eight pistons of an eight-cylinder engine, then, is 216,000 inches ($8 \times 27,000 = 216,000$), or 18,000 feet. Stated in another way, this is equivalent to a single force of 175

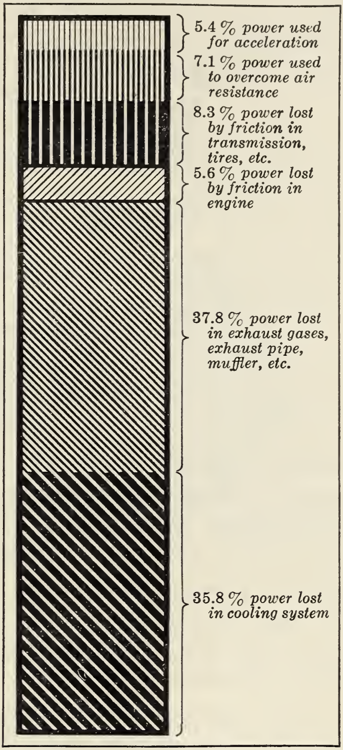


Fig. 211. Even a Gasoline Engine does not deliver All its Potential Energy as Kinetic Energy to the Wheels

What wastes are there here? How do they compare with those shown in Fig. 207? May any of them be overcome?

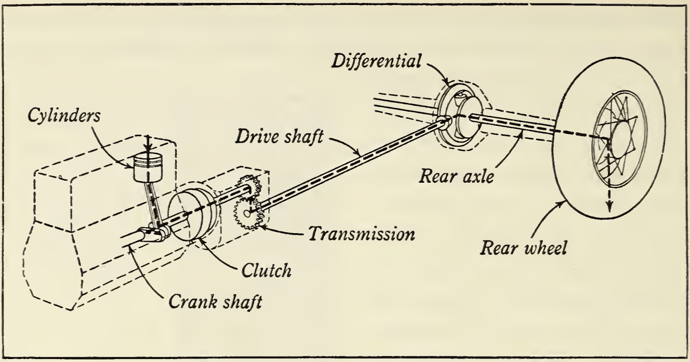


Fig. 212. The Power of an Automobile is transferred to the Wheels through a Succession of Gears and Levers

This diagram shows the skeleton of a car. Can you trace a stream of energy from the engine to the wheels?

pounds acting through this distance in one minute. It is easy to show that this is work at the rate of 3,150,000 foot-pounds per minute ($18{,}000 \times 175 = 3{,}150{,}000$), or about 95 horsepower ($3{,}150{,}000 \div 33{,}000 = 95+$). Not all this power is really delivered to the crank shaft. Some is lost in friction and in other ways, as you can see from Fig. 211. Such an engine would be rated at about 80 horsepower.

The power in an automobile engine is passed on to the wheels by a succession of gears

The ease with which the enormous energy from gasoline may be controlled in a gasoline engine is evidence of man's ability as an inventor. Study Fig. 212. The engine is joined to the drive shaft by the clutch and the gear box. One part of the clutch is attached to the crank shaft of the engine; the other is attached to the clutch shaft, which connects with the gears. When you let the clutch pedal up, the two parts fit against each other so firmly that the parts do not slip. When the clutch is in, it connects the engine with the clutch shaft. A gear wheel on

the end of the clutch shaft fits into a gear wheel in the gear box. This connection is shown in Fig. 214. When you push the clutch pedal down, you disconnect the two parts of the clutch and in this way disconnect the engine and the clutch shaft. The engine and the clutch shaft, then, are disconnected while you are shifting gears.

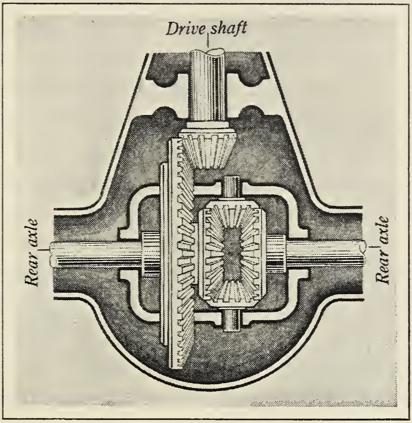


Fig. 213. The Differential in the Rear Axle of an Automobile transfers the Power from the Drive Shaft to the Rear Wheels

Why are these gears called the differential gears?

Power is carried from the gear box to another set of gears in the rear axle, called the differential (see Fig. 213). Since power is carried to the rear wheels through the axle, the axle must be fixed firmly to the wheels and turn as the wheels turn. The rear wheels do not turn on their axles as do the front wheels or as the wheels of a buggy turn. The arrangement of gears in the differential does, however, allow one wheel to turn independently of the other wheel. This is very important, for in going around a turn one wheel must travel farther than the other. The gears of the axle are joined to the gears of the drive shaft in such a way that the drive shaft turns about four and a half times while the axle turns once. The mechanical advantage of the gears in the differential is therefore $4\frac{1}{2}$.

You have learned in a previous chapter about gears. The mechanical advantage of the gears in the gear box when set in low may be 3. If the mechanical advantage of the gears in the differential is $4\frac{1}{2}$, the total mechanical advantage is

$13\frac{1}{2}$ ($3 \times 4\frac{1}{2} = 13\frac{1}{2}$). In other words, the force from the explosion of gasoline in the cylinder, if there were no friction, would be delivered to the rear axle as a force thirteen and a half times as great as the force against the piston when the gears are set in low. The average force of 175 pounds from the explosion of gasoline in the cylinder, then, is delivered to the rear axle as a force of about 2360 pounds ($175 \times 13.5 = 2362.5$). A car rated at 80 horsepower would probably weigh about 4000 pounds. The force that would be delivered to the rear wheel, if there were no friction, would be more than half as great as the force required to lift the car off the ground. This force is sufficient to move the car up very steep hills.

The total mechanical advantage of the driving mechanism is about $13\frac{1}{2}$

If you are familiar with the working of an automobile, you know that you commonly refer to the shifting of gears from first into second, into high, and into reverse. What do you mean? If you could look into the gear box of an automobile, you would find a number of gears, large and small, so mounted that as you shift them the relationship between them changes. Study the diagrams in Fig 214. As you can see, when the engine is running in high, the clutch shaft is joined directly to the drive shaft, and the gears in the gear box are not used. The only mechanical advantage while driving in high is the mechanical advantage of the differential. This, as we have seen, is $4\frac{1}{2}$. If there were no friction, a force of 175 pounds against the piston would be delivered to the rear wheels as a force of about 787 pounds ($4\frac{1}{2} \times 175 = 787\frac{1}{2}$).

In second gear the mechanical advantage in such a car is about $7\frac{3}{4}$. The driving force in second (neglecting friction) is therefore about 1375 pounds.

If the engine is running at three thousand revolutions per minute, the wheels may turn about three times as fast (this figure varies in different cars) when geared in high as when geared in low, but the force delivered to the

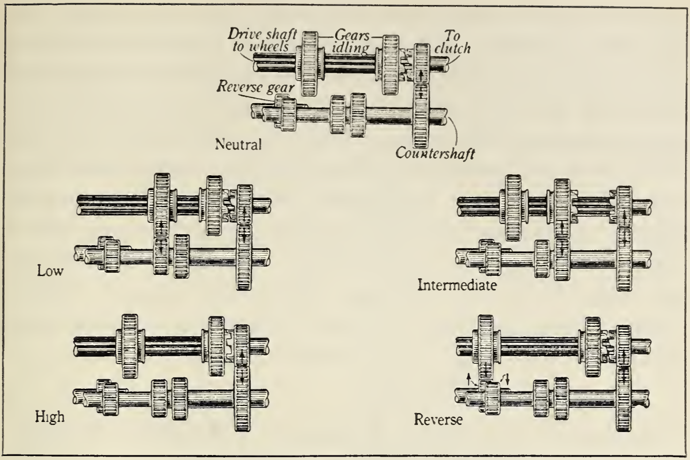


Fig. 214. The Gears of an Automobile are so arranged that as you shift into Different Speeds the Relationship of the Gears to Each Other changes. This in Turn changes the Mechanical Advantage of the Gears

Can you trace changes in the "line of power" for each of the gear shifts?

wheels will be but one third as great. You know that the car moves more slowly in low, and you know that when running in low it can climb a steeper hill or pull a heavier load.

The parts of an automobile must work together; each part must perform its function at the proper instant. If the car is running at high speed, the intake valve of each cylinder must open and admit gas fifteen hundred times each minute. Not only must the valve open, but it must open at just the right time, namely, just at the instant the piston starts downward on the intake stroke. Similarly the exhaust valve must open at the proper instant and allow the products from burning gas to escape. The spark must pass across the spark plug just as the piston starts downward on the power stroke. The timer and the distributor are instruments for controlling the spark, and these are geared to the crank shaft in such a way that the spark can come only at the proper instant.

The moving parts of an automobile are constructed so as to reduce friction. The parts are fitted together with great care and are kept well lubricated. The tires are constructed in such a way that there is as much friction as possible between them and the road. As the car moves forward, the force from the explosion in the cylinder is being transferred through levers and cogwheels (the cogwheels are really levers) to the rear axle and applied in such a way that it causes the wheels to turn forward. Friction with the road prevents them from slipping. Thus every time the wheels turn around, the car is moved forward a distance equal to the circumference of the wheels.

D. How do the Steam Turbine and the Diesel Engine change Energy into Power?

If you were to visit a large electric power plant, you would find that the steam engines used there are of an entirely different type from the one we described in connection with the locomotive. The steam instead of being used to move heavy pistons back and forth in cylinders is used to spin huge turbine wheels. You may demonstrate the principle of the steam turbine by the simple means shown in Fig. 215. The wheel with the blades may be cut from a piece of tin. A cork with a darning needle through it serves as an axle.

In practice, of course, the steam turbine is a very complex piece of machinery (Fig. 216). The blades are turned to an accurate pitch and mounted on a rotating wheel. The moving parts are inclosed in a case. Steam under high pressure issues from the boiler of the turbine engine as a continuous jet, and this jet strikes against the blades, causing the turbine wheel to spin and thus pass on power.

A steam turbine is a more efficient form of external-combustion engine

The efficiency of the steam-turbine engine is greater than that of an engine using cylinders, for the loss of energy is

less than in the cylinder engine. Steam turbines are used to drive steamships, not only because they are more efficient but because they run with less vibration. The generators in electric power plants too are commonly run by steam turbines. The full story of the turbine engine is too complex to discuss here. At this point in your work it is only necessary to recognize the steam-turbine engine as a more efficient machine than the cylinder engine for changing the energy of steam into power.

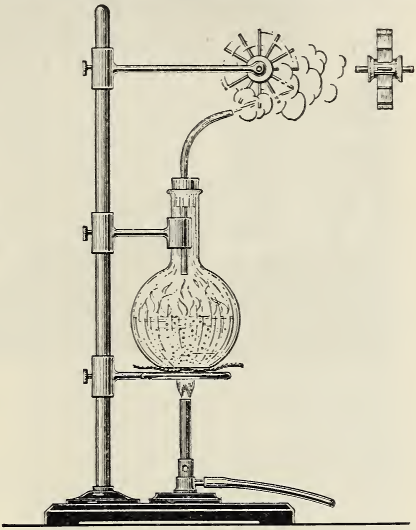
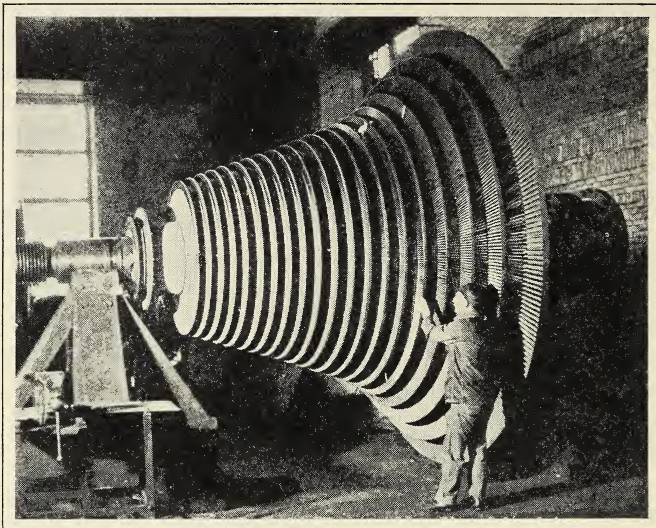


Fig. 215. A Simple Laboratory Experiment will illustrate the Principle of a Steam Turbine

The wheel as shown at the right is made of pieces of tin set into slots on an ordinary spool

The steam turbine represents an important improvement in the external-combustion engine. It has, in fact, revolutionized the use of such engines. Similarly the Diesel engine represents a new type of internal-combustion engine. This new engine has recently come into general notice because it is the source of power for the new high-speed trains. The Diesel is an internal-combustion engine which burns fuel oil. It is similar to the gasoline engine, but differs from it in that the pressure within the cylinders of the Diesel is much greater during and following the explosions. Air is admitted to the cylinder and compressed by the piston to about 500 pounds' pressure. This pressure heats the air to

The Diesel engine is a more efficient form of internal-combustion engine



Ewing Galloway

Fig. 216. The Modern Steam Turbine is a Very Complex Piece of Machinery

This rotating wheel fitted with blades is inclosed in a case. High-pressure steam turns the wheel at great speed

about 600° C. Fuel oil is sprayed into the cylinder from a powerful pump while the hot air is under compression. The temperature within the cylinder is high enough to ignite the fuel oil, and the explosion, or power stroke, follows. Another stroke of the piston clears the burned gases out of the cylinder. Air is again admitted, and the cycle is repeated. No spark plug is used in a Diesel engine. This engine is more economical than the gasoline engine, partly because it uses a much cheaper fuel.

Some extremely careful work was required before the principle of the Diesel engine could be practically applied. The difficulty hardest to overcome was to make a device that would force fuel oil into the cylinder against the heavy pressure of the compression stroke.

E. What are the Characteristics of the New High-Speed Trains?

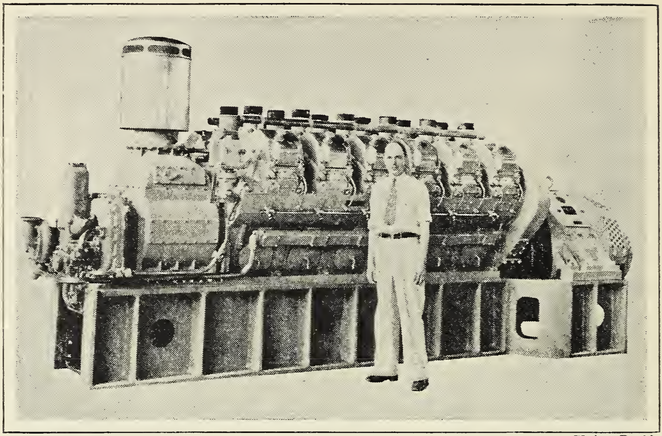
Is the train pictured in the frontispiece of this unit familiar to you? On its first trip across the country this train was observed with tremendous interest, not only by the public at large but by engineers. To many people the train was interesting because of its novel design, its many comforts, and its high speed. To the engineer it had interest because of its efficiency. A few figures will help to bring this out.

Union Pacific

FIG. 217. Cab of a New High-Speed Train

Consider such a train. Even the apparatus in the cab (Fig. 217) seems comparatively simple. The power plant, including Diesel engine and generator, as shown in Fig. 218, weighs a little less than 15 tons. The entire train, including the power car, weighs when fully loaded a little more than 200 tons, or about two thirds the weight of the engine alone in a steam train. The Diesel engine will develop 900 horsepower, or sufficient power to maintain a speed of 90 miles per hour. On its first trip from coast to coast this train averaged a little under 60 miles an hour and at times reached a speed of 120 miles an hour. It carries enough fuel and water for a run of 1200 miles. The

New types of engines and new materials are changing railroad travel



Union Pacific

Fig. 218. The Power Plants of the New High-Speed Trains seem Relatively Simple when compared with those of Steam Locomotives

Can you trace the way in which fuel oil is changed into energy in this Diesel engine?

six-car train may carry 124 passengers in addition to mail, express, and baggage. This is about 1.7 tons of load for each passenger. How does this compare with the load carried by steam trains? And the operating expense? Well, on the first trip of this train across the continent it averaged 1 mile on 1.6 gallons of fuel oil, costing 4 cents a gallon, or a total of about $80 for fuel to carry it across the continent. Railroad men say this train is revolutionary.

And now let us come to our final question. How is it possible to accomplish these improvements? There is a saving in weight. Aluminum alloy and steel of the same dimensions have about the same tensile strength. The density (which determines weight) of aluminum is only about one third the density of steel. The efficiency of the Diesel engine is just about five times the efficiency of the steam locomotive. With less load to move and a more efficient engine the saving in fuel is very great.

Union Pacific

FIG. 219. Streamlining reduces Air Resistance

Streamlining also contributes to efficiency. Notice the picture of the train at the right in Fig. 219. Contrast this with the train at the left. The nose and the tail of the new train are rounded, so that the train slips through the air with the least possible disturbance.

As one studies this new train, one cannot help but contrast the first practical railroad train and the stagecoach. Does the new train usher in a development in railroading comparable to the development of the first twenty-five years of steam railroading?

An engine is a machine which changes the potential energy of fuel into kinetic energy. Engines may be classified as of two types: the external-combustion engine and the internal-combustion engine. Improvements made in these engines, combined with new uses of materials, are changing many of man's uses of energy.

Can You Answer these Questions?

1. What is the essential difference between an internal-combustion engine and an external-combustion engine?

2. Can you trace the cycle by which the potential energy of coal or oil is changed to kinetic energy in a steam engine?

3. What are some essential differences between a Diesel engine and other types of internal-combustion engines? What advantages has it over other types of engines?

4. What figures are used for force and distance in figuring the horsepower of a steam locomotive?

5. How are the principles of a lever applied in carrying force from the piston to the drive wheel of a locomotive?

6. Why do we say that the development of the steam engine has had an important effect upon the economic lives of people?

7. What figures are used for force and distance in figuring the horsepower of a four-cycle engine?

8. How is the horsepower of an automobile engine figured?

9. Can you trace the "power line" of an automobile from the gasoline in the tank to the rear wheels?

10. How does the mechanical advantage of the gears in the transmission of an automobile change as the gears are shifted?

11. What is the difference between the way steam is used in a turbine and the way it is used in a steam engine?

12. What are the chief differences between the new streamline trains and the older types? How do these improvements increase efficiency?

Questions for Discussion

1. Why does an efficient automobile engine need more than one cylinder? Do you think the number of cylinders has any relation to the comfort of the passengers in the car? Is there a relation between number of cylinders and efficiency of the engine?

2. Why is an internal-combustion engine more efficient than an external-combustion engine?

3. Why do the new streamline trains use Diesel engines rather than gasoline engines?

4. Are automobile trucks as efficient as freight trains for the transportation of most goods?

5. What advantages and disadvantages are there in the use of coal as fuel for railroad engines? fuel oil? gasoline?

6. Do you think it would add to its efficiency if a steam locomotive were built with more than two cylinders? Have such engines been built?

7. Do you think it would be possible for an engineer to build a locomotive or an automobile which would have exactly the horsepower that he had decided on? What are some of the factors he would have to consider?

8. At one time some automobiles were run with steam engines. Do you think there were any advantages in this? What were some of the disadvantages?

Here are Some Things You May Want to Do

1. There are, of course, many good books about railroading. You might look up Carter's *When Railroads were New,* Holland's *Historic Railroads,* or Van Metre's *Trains, Tracks, and Travel.* If you want to know about the pony express, look up Chapman's book *The Pony Express.*

2. Find the story of some famous racing car, such as Campbell's *Bluebird,* and see if you can discover how this car differs from the standard automobile in terms of power, engine design, fuel, or methods of steering.

3. This country is not alone in its famous trains. We have such trains as the Twentieth Century, the Broadway Limited, the Chief, the Capital Limited, the Black Diamond Express, the Empire Builder, the Crescent Limited, the North Coast Limited, the Olympian, the Texas Special, and the Continental Limited among others. Some famous European trains include the Flying Scotsman, the Paris Express, and the Trans-Siberian Express. Make a study of some of these trains and see which makes the fastest time, which is the best equipped, and which runs the longest distance.

4. Find figures which will illustrate the growth of railroads in this country. Prepare graphs from these figures.

5. Find similar figures illustrating the growth of the automobile industry.

Chapter XIX · How does an Airplane use Energy?

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176 C KA CS 33 PAID
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SUCCESS FOUR FLIGHTS THURSDAY MORNING ALL AGAINST
TWENTY ONE MILE WIND STARTED FROM LEVEL WITH
ENGINE POWER ALONE AVERAGE SPEED THROUGH AIR
THIRTY ONE MILES LONGEST 57 SECONDS INFORM PRESS
HOME CHRISTMAS  ORVILLE WRIGHT 525P
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Fig. 220. The Telegram announcing the First Flight of the Wright Brothers, sent by Orville Wright[1]

On December 17, 1903, Orville Wright sent to his father in Dayton, Ohio, the telegram which is reproduced as Fig. 220. Newspapers immediately carried the news to the world. This was the first notice to the general public of the successful flight by a heavier-than-air machine carrying a gasoline motor and pilot. In an interview for the press in 1908 Wilbur Wright was asked if he thought an airplane would ever fly the ocean. He replied that he did think so, but that he thought it could not be done by a plane fitted with a gasoline motor!

[1] From *The Wright Brothers, Fathers of Flight,* by John R. McMahon. Courtesy of Little, Brown and Company, publishers.

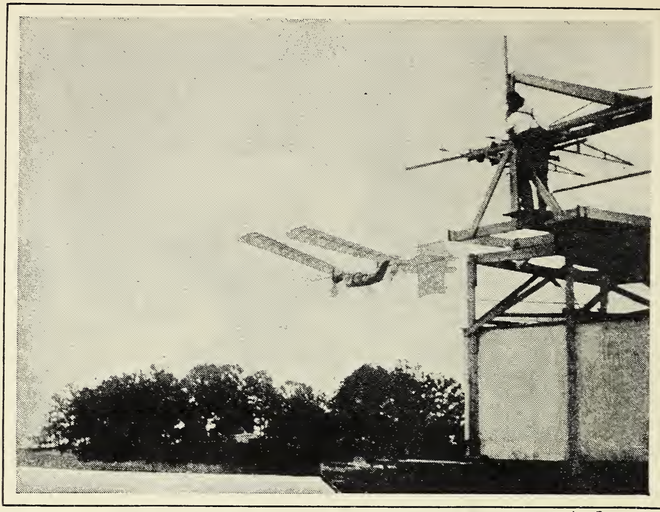
Wide World

Fig. 221. Mr. Orville Wright comparing a Model of his First Plane with a Model of a Plane built Thirty-one Years Later

It is only a little more than thirty years since the Wright brothers made the first airplane capable of flight and powerful enough to carry a man. Their crude machine together with the pilot weighed 750 pounds. It was driven by a gasoline motor of 12 horsepower. The plane was built at Dayton, Ohio, but the test flight was made on a deserted sandy beach near Kitty Hawk, North Carolina, on December 17, 1903. Fig. 221 shows a recent picture of Orville Wright comparing a model of this first plane and a model of a plane built some thirty-one years later.

The development of the airplane is comparatively recent

The successes of the Wright brothers were the result of experiments carried on through several years. These brothers were not the first to experiment with flight in machines heavier than air. Nor was their machine the first to rise off the ground by its own power. If you study the history of the airplane, you will be surprised to learn how much had been done before the time of the Wright



Smithsonian Institution

Fig. 222. Airplane Models powered with Steam Engines were flown successfully before the Opening of the Twentieth Century

This old photograph shows Langley's steam-driven model in flight over the Potomac River in 1896

brothers. Several successful gliders had been made. Their plane was, however, the first to fly and carry a pilot.

Small models driven by simple compressed-air motors had been demonstrated as early as 1848. Models powered with steam engines were successfully demonstrated as early as 1893. In 1896 Langley built a steam-driven machine weighing twenty-six pounds. This one flew by its own power and continued in flight for about one and one-half minutes. It is shown in Fig. 222. In 1903 Langley experimented with an airplane designed to carry a pilot, but his efforts were not successful.

The first flights at Kitty Hawk were the beginning of a great industry. On the day following this important occasion the crude machine was boxed up and returned to Dayton, Ohio, where the Wrights continued their experi-

Smithsonian Institution

FIG. 223. The First Flight across the English Channel in an Airplane was made by Louis Bleriot in 1909

Do you think that Bleriot might accurately be called a brave man?

ments. Improvements now came rapidly. In 1905 Wilbur Wright flew for thirty-eight minutes over a distance of about 24 miles. This was in Dayton. In 1908 the Wrights returned to Kitty Hawk to take further observations on newly developed steering apparatus. Up to this time, however, the Wrights had worked secretly, and the world knew but little of what they had done.

It was about 1908 that competition for new records began. During this year Wilbur Wright flew with a passenger. In 1909 a Frenchman (Louis Bleriot) flew across the English Channel. Fig. 223 shows Bleriot on his historic flight. Ten years later (1919) Alcock and Brown flew the Atlantic from Newfoundland to Ireland. In 1927 Lindbergh flew from New York to Paris.

In 1934 Sir Charles Kingsford-Smith with a companion flew from Brisbane in Australia to Oakland, California, a distance of 7365 miles, with but two stops. He stopped first

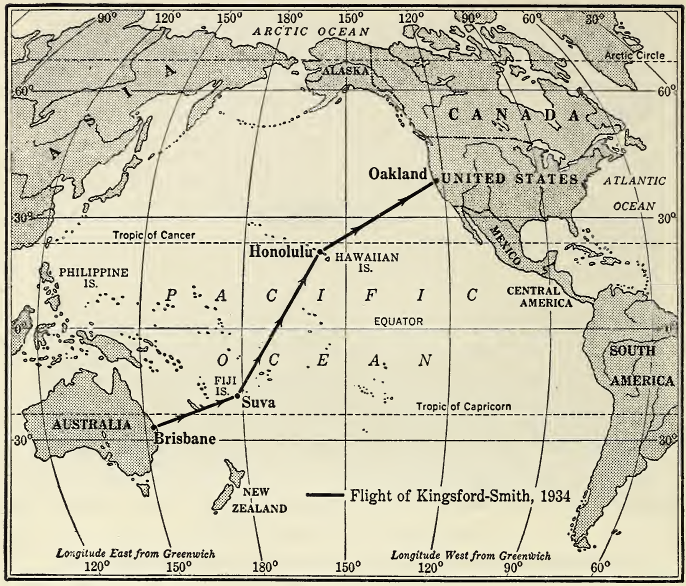


Fig. 224. Modern Aërial Navigation depends upon Accurate Instruments

This map shows the course taken by Kingsford-Smith and his companion in their 1934 flight across the Pacific Ocean from Australia to California. How do you think they kept on a straight path?

at Suva, Fiji Islands, and next at Honolulu. How did he find his way, and how did he keep from getting lost in that broad expanse of the Pacific Ocean? In comparison with the area of the earth these tiny islands seem nothing more than points set in the vast ocean. By means of instruments this skillful aviator set out on a straight line toward his destination. His reckoning was so accurate that he hit squarely upon his goal without turning from his line of flight. Fig. 224 shows the path along which Sir Charles flew. It is a fine degree of control that enables man to achieve this success. And this has come within thirty-one years after the first flight!

Development of better aids to navigation has helped aviation

Ewing Galloway

Fig. 225. The Modern Passenger and Mail Plane is a Far Different Machine from that used by the Wright Brothers or by Bleriot

At any large airport a great number of machines similar to the one shown here arrive and leave on regular schedule

A. How does the Propeller exert a Pulling Force?

If you have ever visited an airport in a large American city, you have seen planes such as the one in Fig. 225 carrying passengers and mail, coming and leaving on regular schedule. These planes may be powered with engines ranging from 100 horsepower upward. A large passenger plane equipped for fifteen passengers has two engines, each of 710 horsepower. One of the largest passenger planes is equipped with four engines capable of developing a total of 3000 horsepower. This, as you may recall, is about equal to the power developed in the steam locomotives used to pull heavy trains.

Suppose you were to examine one of these planes with care. Here is a plane with one engine of 575 horsepower. With its normal load it weighs about 6000 pounds. The

engine, working against air pressure, may lift this load off the ground in a few seconds. The plane may climb at the rate of 1100 feet per minute (faster than the fastest elevator) and fly with a speed of more than 200 miles per hour.

The propeller of this plane is 10 feet long. The total area of the surfaces of the blades is about 2400 square inches. The total air pressure on this surface at sea level is equal to about 36,000 pounds ($15 \times 2400 = 36{,}000$). When the propeller is stationary, this pressure is uniformly distributed. With the engine at full speed, the propeller under 36,000 pounds of pressure cuts into the air like a screw. The powerful engine whirls the propeller 1950 revolutions per minute. At this speed the air pressure against the rear surface of the propeller, just before the plane begins to move, is about 3000 pounds greater than on the front surface. In other words, the forward thrust is 3000 pounds.

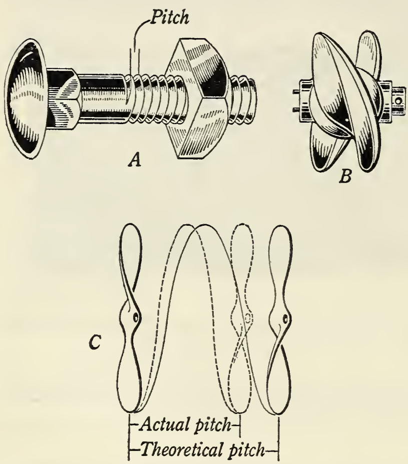


Fig. 226. The Propeller of an Airplane cuts into the Air like a Screw moving into a Nut

A, a bolt and nut. Can you find the pitch of the screw? *B*, a side view of an airplane propeller. *C*, a diagram showing how the theoretical pitch and the actual pitch differ. The actual pitch is the distance the plane moves in one revolution of the propeller

Now let us watch this plane start. In preparation the pilot tests and warms his engine. During this process the wheels are blocked so that the plane cannot move forward. When the pilot runs his engine at full speed, the force of 3000 pounds pushes against the air and causes a strong

current of air to flow toward the rear. If you stand behind the plane, you must hold your hat tightly; else it will be blown away. When all is ready, the blocks are removed from in front of the wheels, and the pilot again speeds up his engine. Now the forward thrust due to difference in pressure between the rear surface and the front surface of the propeller causes the plane to move forward. This forward pull causes a rapid acceleration in the speed of the plane. In a few seconds the plane will be moving forward at a speed of 60 miles per hour. At about this speed the wheels leave the ground.

In England a propeller is called an air screw. The propeller cuts into the air like a screw moving into a nut. This is shown in Fig. 226. The screw propeller of a boat works on the same principle. Since the nut is solid, one turn of the screw carries the screw into the nut a distance equal to the distance between two threads. A bolt (Fig. 226, *A*) may have twelve threads to the inch. In this case the pitch of the screw is one twelfth of an inch, for the nut moves on the bolt one twelfth of an inch for every complete turn. The air screw, or propeller, cuts into the air in the same way; but the air is not solid like the wood or the metal nut, and some of the air slips past it.

An airplane propeller works on the same principle as a screw

B. What is the Horsepower of an Airplane Engine?

The theoretical, or supposed, pitch of a propeller is the distance the propeller would move forward if it were screwed into a solid substance. The *actual*, or real, *pitch* is the distance it does move forward when the plane is in flight in still air. Fig. 226, *C*, may help to explain this. The actual pitch takes into account the fact that air slips past the blades. Engineering principles have shown that the theoretical pitch of a propeller should

The pitch of the propeller has a definite relation to the possible speed of an airplane

be about four fifths of its length. The length is the diameter of the circle in which the propeller turns. If the length is 10 feet, the theoretical pitch is 8 feet ($\frac{4}{5} \times 10 = 8$). One turn of this propeller, then, if there were no air slip, would move the plane forward through a distance of 8 feet. A propeller of these dimensions would be mounted on an engine that would turn at the rate of 1950 revolutions per minute when the plane is in flight. If there were no air slip, this propeller would carry the plane forward 15,600 feet in one minute ($8 \times 1950 = 15{,}600$). Because air slips through the propeller, the airplane would really travel about 75 per cent of this distance, or 11,700 feet, in one minute. This is a speed of about 133 miles per hour $\left(\frac{11{,}700 \times 60}{5280} = 132+\right)$. The pilot would tell you that the cruising speed of this plane is about 140 miles per hour. The greatest speed is about 165 miles per hour.

A forward pull of about 3000 pounds is used to start on the ground a plane weighing 6000 pounds. A continuous pull of about 1000 pounds is required to keep it moving through the air at a speed of 133 miles per hour. These figures furnish a basis for understanding the horsepower requirements of the engine. The work done in one minute is equivalent to a force of 1000 pounds moving through 15,600 feet. This is work at the rate of about 473 horsepower $\left(\frac{1000 \times 15{,}600}{33{,}000} = 472+\right)$. An engine of 575 horsepower delivers about 475 horsepower to the propeller. The remainder (about one fifth) is lost in friction within the engine.

Because of the high speed at which it turns, the propeller is under an enormous strain. One of the difficult problems in airplane construction has been to make a propeller that is strong enough to stand this strain. The tips of a propeller 10 feet in diameter turn through a distance of about 31.5 feet during one revolution. Turning

at 1950 revolutions per minute, the tips move through a distance of 61,425 feet, or nearly 12 miles, in one minute. This is more than 1000 feet in one second, almost as fast as sound travels through air (about 1100 feet per second).

This plane weighing about 6100 pounds will burn about 30 gallons of gasoline per hour and will travel about 150 miles. How does this compare with the amount of fuel used in an automobile of the same weight? A light plane with an engine of 100 horsepower will use 5 gallons per hour and will travel about 100 miles. A plane and an automobile of equal loads, then, give about equal mileage for gasoline used, but of course the plane is faster.

The amounts of gasoline used by an airplane and by an automobile are about equal for equal loads

C. What is the Force that lifts a Plane off the Ground?

You must examine the wings to learn why the airplane leaves the ground. You may see that the wings are slightly curved and that they slope gradually toward the rear of the plane. When the plane is at rest on the ground, the air pressure of 15 pounds per square inch, or 2160 pounds per square foot, is distributed uniformly over the whole surface. When the plane is in motion, the pressure is not uniform over the whole surface. As it moves forward, air is forced away from the top surface of the wings. As the speed increases, the pressure on the top surface becomes continually less than 2160 pounds per square foot. Fig. 227 shows how the pulling forces and the lifting forces of an airplane are distributed while the plane is in flight. The forward thrust of the propeller is about 1000 pounds. The area of the plane surface in one airplane of 575 horsepower and weighing about 6000 pounds is 313 square feet. The average lifting force per square foot is therefore about 19 pounds ($6000 \div 313 = 19+$).

The difference in air pressure on the upper and the lower surface of the wings supports the airplane in the air

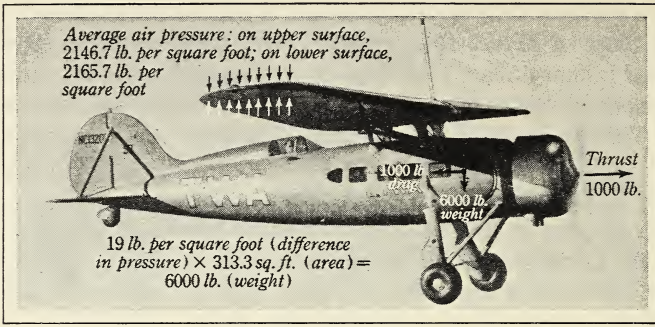


Fig. 227. When an Airplane is in Motion, Air Pressure is not Uniform over the Whole Surface

Under ordinary conditions about 70 per cent of the lifting force comes from the decrease in air pressure on the upper surface of the wing, and about 30 per cent comes from the increase in pressure on the undersurface. The decrease in pressure on the upper surface is about 13.3 pounds per square foot ($0.70 \times 19 = 13.3$). The increase in pressure on the undersurface is about 5.7 pounds per square foot ($0.30 \times 19 = 5.7$). Suppose that air pressure is just 2160 pounds per square foot. When this airplane is in flight, the average pressure on the top surface of the wings will be 2146.7 pounds per square foot ($2160 - 13.3 = 2146.7$). The average pressure on the undersurface will be 2165.7 pounds per square foot. The difference in pressure of 19 pounds per square foot carries the plane in the air. The two forces acting upon an airplane to keep it in the air have their origins in the gasoline that is burned in the cylinders of the engine. One of these forces acts as a pull that moves the airplane forward. The other acts as a push against the undersurface of the wings and lifts the plane off the ground.

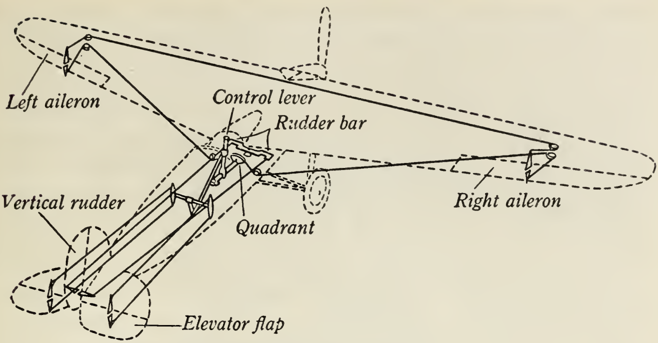


Fig. 228. An Airplane is steered by the Application of Devices which change the Air Pressure on Various Parts of the Plane

See if you can explain how the steering is done by means of the instruments shown in the diagram[1]

D. How is Direction of Flight Controlled?

The main features with which the pilot controls an airplane in flight are the elevator on the tail, the two ailerons (one on each wing), and the rudder. These are shown in Fig. 228. By lowering or raising the elevator the plane is made to go higher or lower. When the elevators are raised, the air strikes against the top surface and forces the tail downward. As the tail is lowered, the nose of the plane must turn upward. With the nose pointed upward the plane rises. When the elevator is lowered, the air strikes against its undersurface in such a way that the tail is raised. This causes the nose of the plane to point downward. With the nose pointing downward the plane moves toward the earth. When the vertical rudder is turned to the left, the air strikes it in such a way that the air forces the tail to the right. This causes the plane to turn toward the left. When the rudder is turned toward the right, the air causes the plane to move toward the right.

[1] From *Skycraft*, by Augustus Post. Courtesy of Oxford University Press, publishers.

The operation of the ailerons is not quite so simple as the operation of the elevator and the rudder. When the airplane is turned, it must be banked to keep it from skidding and turning over. For turning to the left the right wing must be raised and the left wing lowered. This raising or lowering of the wings is accomplished by means of ailerons. In turning to the left the right aileron is lowered so that air strikes with greater force against its lower surface. At the same time the left aileron is raised so that air strikes with less force against its lower surface. This causes the left wing to go lower. At the same time, of course, the right wing goes higher. In this manner the plane is banked as it swings along a circular path.

The control of an airplane in flight is accomplished by mechanisms which change the air pressure to which various parts of the plane are subjected

E. How Fast may we Travel?

The speed at which an airplane may travel depends upon the manner in which it is constructed and the horsepower of its engine. Planes used for carrying passengers travel at speeds between 150 and 200 miles per hour. They can carry between 15 and 25 pounds of weight for every square foot of wing space. One horsepower will carry about 10 to 12 pounds. The fastest planes carry the largest load per square foot and the least load per horsepower. In other words, the faster planes have higher-powered engines and smaller wing surfaces per load than the planes that move more slowly.

The airplane is the fastest machine yet constructed. An airplane powered with a motor of 3500 horsepower has flown on a straight course as fast as 440 miles per hour, or more than 7 miles in one minute. It is hard to imagine how it would feel to travel so fast. A pilot could not ride at this speed in an open cockpit, for he would be killed by the force of the air pressure against his body. If he were

Keystone

Fig. 229. Streamlining of Planes increases their Speed

This plane holds a world's speed record

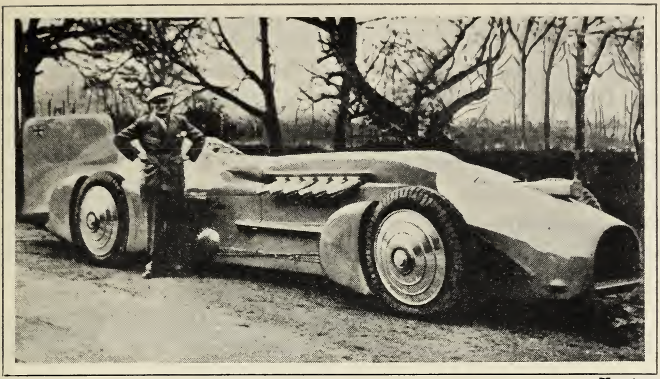
to extend his hand outside the cockpit, the force of air pressure against the flat surface would be about 90 pounds per square inch. Applied against the palm of the hand and the open fingers, this would be a total pressure of about 2000 pounds. This pressure would certainly break the bones in the hand. Of course the plane was streamlined so that no flat surfaces were exposed to catch the wind. The plane cut through the air with the least possible resistance. Such a streamlined plane is shown in Fig. 229. If the pilot were to turn the plane from a straight line while traveling at this speed, the change in direction would interfere seriously with the circulation of his blood. Centrifugal force would carry so much of the blood to the side of his body that was on the outside of the turn that he would probably lose consciousness. He would, however, ride in comfort so long as he continued in a straight line. It has been predicted that stratosphere planes may sometime be constructed that will fly through the upper air as fast as

500 or more miles per hour. If such planes are ever made, the courses along which they fly must be straight lines; else the human body could not live through the experience.

As you review the progress of mankind in control and use of energy for transportation, you may ask what the future holds in store. May we expect further increases in speed of trains, automobiles, and airplanes? As we anticipate the future, we must make predictions. But predictions are made on the basis of what is known at the present and are frequently in error. When Wilbur Wright made his prediction (in 1908) about the future of airplanes, he did not imagine that the small engine furnishing power for his plane would develop into the powerful engines of today. An equally inaccurate prediction was made by Lord Kelvin (a famous British scientist born in 1824) when he said that no steamship could ever cross the ocean because the weight of the coal required to drive it would sink the ship.

It seems impossible for any form of land transportation to achieve the speeds reached by air transportation

The greatest speed ever reached on the ground is 276 miles per hour. This was made by the racing car shown in Fig. 230, at Daytona Beach, Florida. May we expect regular cars to travel so fast? It does not seem likely. The racing car was built to race for just one minute and a half. The strain on the machinery was so great it would certainly have broken down before fifteen minutes. At 245 miles per hour the wheels made 2300 revolutions per minute. Heavy tires such as those used on ordinary cars would have been flung off by centrifugal force. The light tires used on the car would not stand up for more than four minutes. The tail of the car was constructed to hold it on the ground and to keep it in its course. Only a little change from a straight line would probably throw the car out of control. It hardly seems likely that the speed on the open road can ever increase very much over what it is now.



Keystone

Fig. 230. This Streamlined Car made a Speed of 276 Miles Per Hour

It was driven by Sir Malcolm Campbell, an Englishman, and was called the *Bluebird*

The new streamlined trains will certainly increase the rate of travel by rail. Some of the obstacles preventing increases in speed of automobiles do not apply when wheels are made to run on rails. Train speeds up to at least 150 miles an hour seem reasonably possible.

May we expect the airplane record for racing speed ever to become common? It seems likely that we may. The time is probably not far distant when airplanes will fly through the stratosphere at an altitude of possibly 50,000 feet. At this altitude air is but one ninth as dense as at sea level (Fig. 173, p. 318), and in this thin air airplanes can certainly travel very much faster than they can travel in the denser air near the earth.

What further controls must be achieved to make such flight possible? The oxygen in this thin air is not sufficient to keep the engine running. Superchargers (instruments for compressing the thin air and pumping it into the engine) have been used for high-altitude flights. It may be necessary to carry pure oxygen for the engine during flights into the stratosphere. Passengers and crew must be sealed in

their gondolas. A supercharger may be used to maintain the air within the sealed gondola at a pressure the same as normal atmospheric pressure. Principles underlying these developments are known, and energy for their achievement can be easily found. It only remains for engineers to make the practical applications. These will not be the work of one engineer alone. Doubtless many will contribute. But this development will surely come. The time is probably not far distant when travelers may breakfast in New York and dine in London.

There has been great progress in control of energy since Stephenson built the first locomotive. Effects of this progress in control are abundantly seen in the changing means for transportation.

The development of the airplane is comparatively recent. Air pressure causes an airplane to leave the ground and to move through the air. The possibilities of more rapid transportation depend upon the future development of the airplane.

Can You Answer these Questions?

1. What is the forward thrust of a propeller?

2. What is the difference between the actual pitch and the theoretical pitch of an airplane propeller?

3. Is there any difference between the way in which horsepower is calculated for an airplane engine and the way it is done for an automobile engine?

4. Which gives the larger lift in keeping an airplane in flight, the decrease in pressure on the upper surface of the wings or the increase in pressure on the lower surface?

5. How is direction of flight of an airplane controlled?

6. What are some of the physical difficulties which must be considered in high-speed airplane flight?

Questions for Discussion

1. Do you think it is correct to call the Wright brothers the inventors of the airplane? Compare their work with the work of Langley.

2. What should you say have been some of the important steps in the development of the airplane?

3. One of the recent improvements in the airplane is a propeller whose pitch may be changed while in flight. What advantages has this propeller over one with a fixed pitch?

4. Which is more favorable for the take-off of an airplane, a head wind or a tail wind?

5. Why do gliders stay up?

Here are Some Things You May Want to Do

1. Should you like to know more about the history of aviation? Read Goldstrom's *A Narrative History of Aviation.* Should you like to make airplane models? A good book is Garber's *Building and Flying Model Aircraft.* If you want to know more about the technical matters of flight, you will find them simply explained in Post's *Skycraft.* And if you are a girl and feel that you are not interested in these things, you may enjoy Amelia Earhart's *For the Fun of It.*

2. Make a special study of the autogyro and report on it in class. Consider such things as how it differs from a regular airplane, some of its advantages and disadvantages, and how its flight is controlled.

3. Many boys and girls today belong to model-airplane clubs. They build their own airplanes and have regular competitions for prizes. Perhaps some teacher in your school would be willing to help you to organize such a club.

4. In this chapter we mention the flight of Kingsford-Smith. It was only one of many that have depended upon accurate navigation. Do you know how an aviator finds his position and holds to a charted course? See what you can find out about this.

5. Make a study of some of the famous long-distance flights and prepare some short talks to present in class.

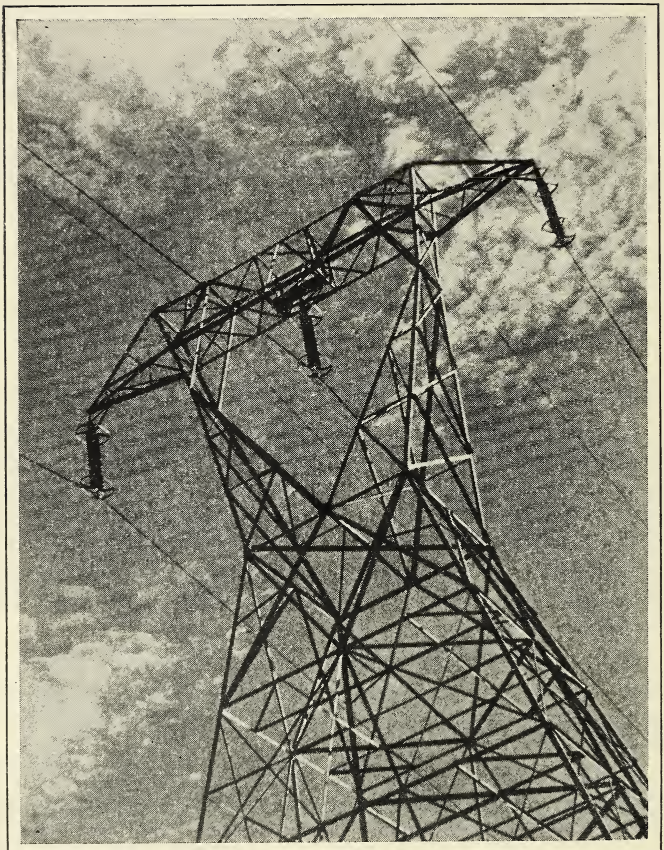


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Fig. 231. Today Thousands of Miles of High-Tension Wires carry Electrical Energy to All Parts of the Land

UNIT V

How has Man gained Control over Electrical Energy?

Chapter XX · What are Some of the Characteristics of Electricity?

Chapter XXI · What is the Nature of Current Electricity, and How is it used to do Work?

Chapter XXII · How is Electrical Energy generated from Coal and Falling Water?

Chapter XXIII · How is Electrical Energy used in the Telephone and Radio?

OF THE things you have used today, how many are useful because of electricity? No doubt it would make a long list if you were to name them all. We accept these things as ordinary, and yet most of them were unknown during the boyhood of your grandfathers. The electric motor was invented in 1837, but it was little more than a toy until after 1880. The first light bulbs were made in 1880, and the radio has come into common use almost during your own lifetime.

The common electric lamps would have been of no use previous to 1880, for there was no current for lighting them. Simple batteries were in use, but these could not supply enough energy to light streets and homes. The first electric generator designed to supply current for offices and homes was set up in 1882. It was built in New York City by Thomas A. Edison, and it served an area of about twelve city blocks. Today electrical service reaches about three fourths of the entire population of the United States.

During the period of development of the light and power industries, other great electrical industries came into being. The first telephone was made in 1875; so the telephone was a novelty when the light bulb was invented. The radio tube was invented in 1906, but its wide use in broadcasting and receiving sets did not come until after 1918. A simple machine for motion pictures was shown in 1889, but the first practical machine came in 1895. The first sound films were shown in 1926.

With this brief review of the growth of electrical industries, you may wonder what the next years will bring forth. Is it likely that equally great developments will come during your lifetime? May you have a part in this development? Your study of this unit should help you to think clearly about these questions.

Chapter XX · What are Some of the Characteristics of Electricity?

Electricity is a form of energy that man has only recently learned to control. You see its use everywhere. Electrical energy comes into your house and is measured in terms of the amount of work it does.

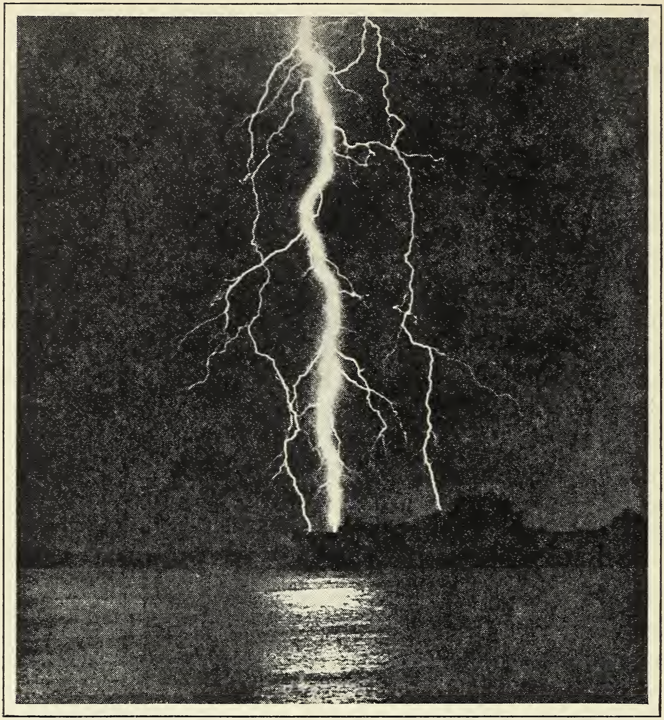
You may generate frictional electricity by rubbing your coat sleeve (if your coat is made of wool) with the barrel of your fountain pen. You may use the energy of a dry cell or of a storage battery in ringing a doorbell or blowing an automobile horn. You may stand on a mountain top and see lightning play around the black edges of distant clouds which announce the approach of a thunderstorm. Perhaps you have seen it as shown in Fig. 232. All these phenomena are evidences of electrical energy.

The story of electricity is interesting because it is a tremendously important factor in life today. Man had to learn many things about electricity before he was able to control and use it. Some of this information was gained only after long study and many experiments. The answers to some questions about electricity, however, which seemed extremely difficult only a short time ago, are now common knowledge. Let us see what we can find out about electricity.

What does the Behavior of Charged Bodies teach us about Electricity?

The Greeks had some knowledge of electricity

The fact that man has been able to make efficient use of electricity only within the last fifty years does not mean that he did not know anything about it before that time. Early records show that the Greeks, some three or four hundred years before the birth of Christ, described some of the properties of electricity. They knew the gum called amber



Keystone

FIG. 232. Lightning is a Familiar Form of Electrical Energy

and used it for making ornaments and trinkets. They knew that an amber rod rubbed with fur would pick up or attract certain light objects such as paper. The court physician during the reign of Queen Elizabeth called this attraction *electric*. The word *electric* comes from the Greek word for amber.

In America, Benjamin Franklin became interested in electricity. You may know Franklin as one of young America's prominent men in government, but he was also one of her leading scientists. You may have seen pictures

of Franklin flying a kite during a thunderstorm. Have you ever wondered why Franklin was doing this? He had been puzzled about lightning and wanted to find out about it for himself.

Franklin was a pioneer experimenter in electricity

Today it is obvious that Franklin took many chances in studying electricity. Indeed it is a wonder he wasn't killed, for his experiments with lightning were probably far more dangerous than he knew. Through his experiments, however, he proved that the streak of lightning and the spark from a stick of amber are similar phenomena. His experiments and those of many other investigators are the foundations upon which the present knowledge of electricity has been built.

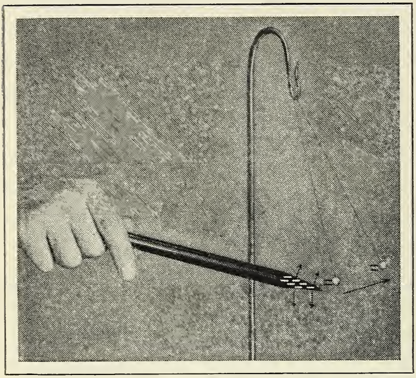
It was soon found that hard rubber, sulfur, and glass, when rubbed in the same way as amber, produced similar results. Perhaps you would like to repeat some of the experiments of the early experimenters in electricity.

Objects may be charged with electricity

Take a rod of hard rubber (a fountain pen or a hard-rubber comb) and rub it vigorously with a piece of fur (or wool). Does the rod attract bits of paper? Now hang a dry pith ball (pith is the light substance you find in the hollow stems of plants) from a support by means of a silk thread. After the rod has been rubbed with fur, bring it close to the ball and hold it as shown in Fig. 233. Notice that the ball is first attracted to the rod. After the ball has touched the rod, move the rod away from the ball and then bring it close to the ball a second time. This time the ball is repelled, as you can see from the photograph. Repeat this experiment, using a rod of glass which has been rubbed with silk. You will probably find that glass rubbed with silk does not attract or repel as strongly as rubber rubbed with fur. You will notice, too, that you get best results on a day when the humidity in the room is low. However, observe that you get similar results in each case. What is the explanation? You can answer this after a little more experimenting.

Hang from a support a rubber rod that has been rubbed with wool. Give a charge to a second rubber rod in the same manner and bring it near the first one, as shown in Fig. 234. Notice that one rod repels the other. Repeat this experiment, using two glass rods that have been rubbed with silk. Again notice that one rod repels the other. Try one more combination. Hang the charged rubber rod on the support and bring up to it a charged glass rod. What happens this time? You can see that the charged glass and charged rubber rods attract each other. You have seen now that a charged glass rod will repel another charged glass rod; a charged rubber rod will repel another charged rubber rod; but between a charged rubber rod and a charged glass rod there is an attraction.

Some charged objects attract each other. Some repel each other



Ewing Galloway

Fig. 233. Objects may be charged with Electricity

Notice that, after the pith balls have become charged with negative electricity from the rubber rod, they are repelled

You may study other substances experimentally. Will the charged rods pick up little wads of cotton? Try tissue paper, aluminum foil, cork filings (made by rubbing a file over a piece of cork), or any other light substance that is at hand. Can you charge a metal rod by rubbing it with silk or fur? Try a wax candle or a stick of sealing wax.

Franklin thought that there were two different kinds of electricity

Franklin decided from these and other similar experiments that there are two different kinds of electricity. One kind is formed on glass by rubbing it with

silk. The other is formed on rubber by rubbing it with fur. He found, too, that the silk and the fur also became charged. The charge on the silk was not the same as that on the glass, however, and the charge on the fur was not the same as the charge on the rubber. In fact, the opposite was true. The charge on the silk was similar to the charge on the rubber, and the charge on the fur was similar to the charge on the glass.

Electricity is positive and negative

Since the charges seemed opposite in character, Franklin called one (the charge on glass or fur) positive electricity and the other (the charge on rubber or on silk) negative electricity. Since the electricity seemed to stay on the glass or rubber rods after they were once charged, it was named static electricity. *Static* is from a Greek word meaning "causing to stay." According to the electron theory, electricity on glass and rubber is the same as other electricity.

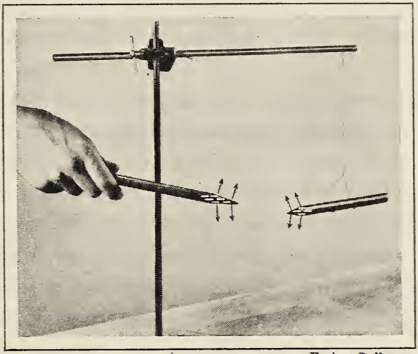


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FIG. 234. Why do these Charged Rubber Rods repel Each Other?

Not all kinds of materials hold an electric charge as rubber and glass do. You cannot charge a metal rod by holding it in the hand and rubbing it with silk or fur or anything else. Any charge that is formed on these substances runs off. Metals, then, are conductors of electricity. Substances like glass, rubber, silk, paper, and pith, however, are called nonconductors, or insulators, for they do not conduct electricity. In this instance electricity is static; that is, it "stays on" a nonconductor.

Some materials are conductors of electricity. Materials over which electricity does not flow easily are called insulators

It is possible to tell what some insulators will do when they are charged with electricity, for under the same conditions they always behave in the same way. You have observed the behavior of rubber charged by rubbing it with wool or fur, and you have observed the behavior of glass charged by rubbing it with silk. You may summarize your observations as follows:

The behavior of charged bodies may be predicted

1. An uncharged body is attracted by a charged one. Little bits of paper, pith balls, and other things that are nonconductors of electricity are attracted by either a charged glass rod or a charged rubber rod.

2. When two bodies are charged alike (both positive or both negative), there is a repelling force between them. There is a repelling force between a charged glass rod and another charged glass rod. There is a repelling force between a charged rubber rod and another charged rubber rod.

3. When two bodies carry unlike charges (one positive and the other negative), there is an attractive force between them. There is an attractive force between a charged rubber rod and a charged glass rod.

4. When an uncharged body is touched by a charged one, part of the charge passes to the uncharged body. Remember how the pith ball was first attracted to the rubber rod and was then repelled? The charged rubber rod contained negative electricity. The pith ball was uncharged. According to 1 there should have been an attractive force. Was there? After touching the charged rubber rod, however, the pith ball became charged with negative electricity. In other words, both the rod and the pith ball contained negative electricity. If 2 is correct, the two objects should then have repelled each other. Did they?

A charge may pass from one body to another

If you will consider what you have found from your experiments, it becomes evident that there is energy on the surface of the charged rods, for they will exert a push or

a pull on some objects. This energy is electricity. It is formed on the rubber rod by friction with fur, and on the glass rod by friction with silk. Thus the energy of motion has been changed to electrical energy. It has been estimated that a large airship may become charged by friction with air to such a degree that the attraction between it and the earth, owing to the electrical charges, may reach two or three hundred pounds. Where does this electrical energy come from? The answer may be found in a theory which seems to explain these observations and many others.

The energy on charged bodies is electricity

You are already familiar with the theory which supposes matter to be made up of atoms, which in turn are made up of tiny particles called electrons and protons. Electrons, as you have learned, are particles of negative electricity; and the protons are particles of positive electricity. It is further supposed that the charge on an electron is just equal and opposite to the charge on a proton. It is supposed, too, that an atom normally has just as many particles of positive electricity (protons) as it has of negative electricity (electrons). In other words, an atom is neutral, for it is neither positive nor negative. Be sure that you understand this, because it is important in the explanation that follows.

An atom is a neutral particle

Imagine now that something disturbs this balanced arrangement. Under certain conditions some atoms will lose electrons while other atoms will gain electrons. When either happens, the atom is no longer neutral. An atom which has gained or lost electrons is called an ion. If it loses electrons, the part that remains is a positive ion (neutral − negative = positive). When the atom gains electrons, the result is a negative ion (neutral + negative = negative). Let us use this theory to explain the observations you made in your experiments with static electricity.

When atoms lose or gain electrons, they become ions

The atoms in all the substances you used were neutral.

After you rubbed the glass rod with silk, however, you found that the rod was positive and the silk negative. What had happened? According to the electron theory electrons passed from the glass rod to the silk. Do you see how this explains the formation of opposite charges? After you rubbed a piece of rubber with fur, the rubber was negative and the fur positive. How should you explain this?

Now recall what happened when the rubber rod was brought near a pith ball. Remember that the pith ball was neutral and the rubber rod negative. When the rod first approached the pith ball, there was obviously an attracting force between the ball and the rubber; but after the ball had touched the rubber, there was then a repelling force between them. Can you explain this?

The behavior of charged bodies may be explained in terms of the electron theory

First explain why the neutral ball is attracted, using the rules (p. 428) established by experiment and the theory we have just outlined. You can do this by supposing that the electrons on the rubber rod repelled some of the electrons on the pith ball to the far side of the ball (2, p. 428). This would leave the side nearest to the rubber rod with fewer electrons; that is, it would be positive. You have found that unlike charges attract (3, p. 428). So you may expect the pith ball to be attracted to the rod (1, p. 428). Now let us explain why the pith ball was repelled after having touched the rubber rod. When these two objects came in contact, electrons passed from the rubber rod to the pith ball. The neutral pith ball had negative electrons added to it, and thus it too became negatively charged. What happens when similarly charged bodies are near each other (2, p. 428)? If you have tried to pick up little pieces of paper with a comb or a fountain pen that has been rubbed with wool, you may have noticed that sometimes a piece of paper would be attracted to the rubber, stick to it for a second or two, and then drop off again. Can you explain this now?

Recall your experiences with the glass rod and the pith ball. They were exactly the same as those with the rubber rod, were they not? In this case the pith ball was again neutral, but the glass rod was positively charged as a result of losing electrons. Again the objects attracted each other. Can you explain why? When they came in contact, electrons passed from the pith ball to the glass rod. Thus the pith ball, losing some electrons to the glass rod, became positively charged. What happens when similarly charged bodies approach each other? Can you explain what happened to the rods shown in Fig. 234?

You may wish to repeat your experiments with the different types of objects, and see whether you can explain all your observations by using the electron theory.

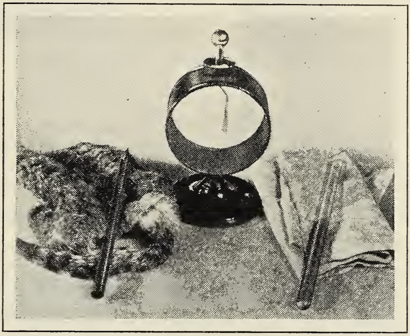

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Fig. 235. An Electroscope is a Convenient Instrument for Studying Charged Bodies

Rubber is charged with fur, glass is charged with silk

An electroscope is a most convenient instrument for studying charged bodies. As shown in Fig. 235, it consists of a metal rod carefully insulated from its surroundings so that any charge on it cannot readily run off. It is inclosed to protect it from air currents. Attached to the end of the rod is a leaf of metal foil. Gold leaf or aluminum foil is commonly used. Thus electrons flow freely over the rod and the metal leaf, which are conductors; but they cannot escape, for the rod is mounted in insulating material.

A satisfactory electroscope may be made by fastening a heavy piece of iron wire through a rubber stopper and extending the wire into a bottle, as shown in Fig. 236.

Bend the end of the wire into a hook, and hang a strip of gold leaf or aluminum foil over the hook so that about an inch of the metal strip hangs down on each side of the hook. This must be done in a place where there are no air currents to blow the metal foil while it is being handled. Care must be used, for the metal foil is easily destroyed.

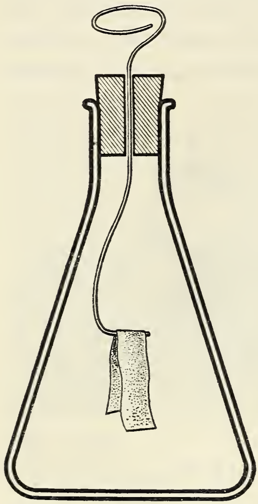

Fig. 236. A Satisfactory Electroscope may be made from a Flask or Bottle, a Cork, a Piece of Iron Wire, and a Strip of Gold Leaf or Aluminum Foil

The following four experiments may be done with an electroscope. Under each one an explanation is given of what happens and why. Read them carefully and study the diagrams.

1. Start with a rubber rod and an electroscope as shown in Fig. 237. In this picture neither is charged. Now charge the rubber rod by rubbing it with fur and bring the charged rubber toward the knob of the metal rod of the electroscope (as in Fig. 238). Notice that the leaves of the electroscope spread. Why should this be? The rubber rod, as you have learned, is negatively charged; that is, it carries more electrons than are carried on an uncharged rod. As the rod approaches the electroscope, this extra supply of electrons on the rubber rod drives electrons from the knob of the electroscope toward the leaves. Thus the knob loses electrons and becomes positively charged. The leaves now have more electrons than normally and therefore are negatively charged. They repel each other and the metal foil spreads out like a V turned upside down.

2. Repeat this experiment, but this time use a charged glass rod. Notice that the results are the same. In this

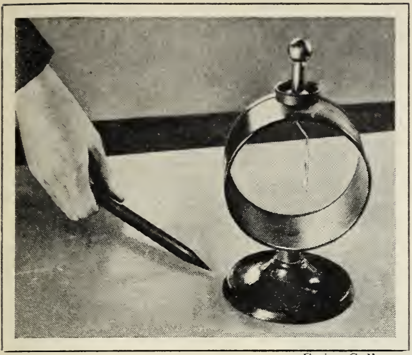

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FIG. 237. Neither the Rubber Rod nor the Metal Rod of the Electroscope is charged. Electrons are distributed through Both

case you know the glass rod is positively charged; that is, it has fewer electrons than normally. As the rod approaches, electrons are attracted toward it. They move up the metal rod of the electroscope toward the knob. Thus the knob becomes negatively charged (with more electrons than are normally there). The leaves, however, become positively charged, having lost electrons by the flow toward the knob. Since both of them are positively charged, they repel each other.

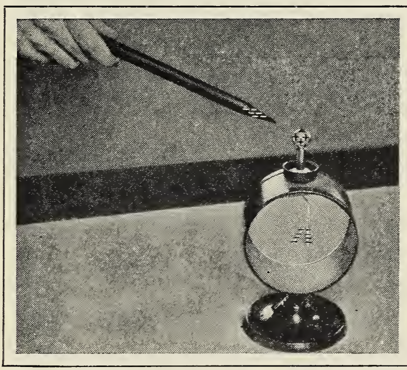

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FIG. 238. Electrons from the Knob are driven toward the Leaves of the Electroscope

Thus both of the latter become negatively charged. Since similarly charged bodies repel each other, the leaves spread out

3. Repeat experiment 1. Remember that the electrons are driven away from the knob and toward the leaves. Now while the leaves are spread far apart, touch your finger to the knob of the electroscope. Notice that the leaves collapse. Why is this? The human body is a good conductor of electricity. When the finger is touched to the insulated metal rod, electrons may pass to it from the rod. When

the leaves were as described in 1, there was an extra supply of electrons on the leaves. When your finger touched the knob, however, electrons driven by the negatively charged rubber flowed from the leaves and the rod through your finger and through your body to the ground, thus reducing the electrons on the rod. After electrons had left the leaves, they became neutral again and did not repel each other, so they came together. Fig. 239 pictures this.

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Fig. 239. The Charged Rubber Rod forces Electrons to flow away from the Knob through the Finger

While the finger touches the knob no charge is shown on the leaves

4. After the leaves have collapsed as they did in experiment 3 but while you are still holding the rubber rod near the knob of the electroscope, remove your finger. Notice that the leaves are still collapsed. Now take away the charged rubber rod. Notice that the leaves spread apart. Why should this be so? When the leaves collapsed, they were neutral. Some electrons had left the electroscope through your hand, but owing to the presence of the charged rubber rod more electrons were crowded down to the leaves than were in the knob. The leaves were neutral, but the top of the rod was positive. When the charged rubber rod was removed, however, the electrons which had been repelled to the leaves of the electroscope moved upward again and distributed themselves through the entire rod and the leaves. As some of the electrons had previously flowed off through your finger, however, there were not enough left to balance the protons exactly. In

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FIG. 240. There is a Charge on the Metal Rod but it doesn't show on the Leaves while the Charged Rubber Rod is Near. Why? The figure shows a positive charge on the knob and no charge on the leaves

other words, there was a lack of electrons all over the rod, and the electroscope was positively charged. Now the leaves spread apart again, for they both had a smaller than normal supply of electrons (see Figs. 240 and 241).

You may repeat experiments 3 and 4, using a glass rod charged by rubbing it with silk, instead of rubber charged by rubbing it with wool. The results will be similar except that the charges will be opposite in character.

There are many other interesting experiments that may be planned with an electroscope. Try to arrange some of your own, using variously charged articles in different combinations. Try to explain in terms of the electron theory what happens.

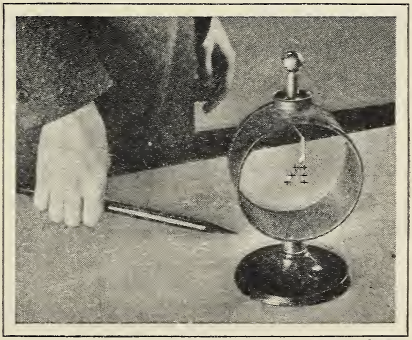

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FIG. 241. Why should the Leaves of the Electroscope spread when the Rubber Rod is taken Away?

Compare with Fig. 240

You know of course that no one has ever seen an electron and that there is no positive proof that such a thing really exists. What we do know is that things behave as

if there were particles moving about as we have imagined that the electrons do. Theories cannot be said to be true or false. They are good or bad suppositions. The more things that can be explained by them the better they are. If things happen which cannot be explained by accepted theories, we know that the theories are incomplete and that more experiments must be performed to suggest ways of improving them.

The electron theory serves to explain the phenomena of static and of current electricity. As you go forward in the study of electricity, you will find it useful in explaining all sorts of electrical phenomena.

Electricity is another form of energy which has its origin in solar radiation. Electricity is found in two forms: positive and negative. The phenomena associated with static electricity may be explained by the use of the electron theory.

Can You Answer these Questions?

1. Is the electrical charge on glass positive or negative? on fur? on rubber? on silk?

2. What is the definition of a nonconductor of electricity? of a conductor?

3. What happens when an uncharged body is brought into contact with a charged one?

4. Do two bodies positively charged attract or repel each other? Why?

5. Do two bodies negatively charged attract or repel each other? Why?

6. Do objects with unlike charges attract or repel each other? Why?

7. What demonstrations should you use to support your answers to 3, 4, 5, and 6?

8. According to the electron theory, what is an atom?

9. Why is an atom normally neutral?

10. What is an ion, and how is it formed?

11. When is an ion negative, and when is an ion positive?

12. Can you explain in terms of the electron theory what happens in 3, 4, 5, and 6 above?

13. What is an electroscope?

14. Can you explain in terms of the electron theory the following demonstrations with an electroscope?

a. A charged rubber rod is brought toward the knob. The leaves spread.

b. A charged glass rod is brought toward the knob. The leaves spread.

c. *b* is repeated, but the knob is touched with your finger. The leaves collapse.

d. *c* is repeated, but your finger is removed. The leaves remain collapsed. The rod is moved away, and the leaves spread.

15. Is there a difference between static electricity and current electricity? Explain.

Questions for Discussion

1. Why should some objects hold negative electricity and others hold positive electricity?

2. What do you think is the reason why some objects will conduct electricity while others will not?

3. Is most of the space inside the atom empty space or is it mostly filled with electrons and protons?

Here are Some Things You May Want to Do

1. If you have an encyclopedia in your school library, see if you can find out what ancient peoples believed about electricity.

2. Suppose an electroscope is charged. You have a rubber rod, a glass rod, a piece of silk, and a piece of fur. How could you find out whether the charge on the electroscope is positive or negative?

3. Charge an electroscope and leave it charged. Will it hold the charge indefinitely? Try it and see if you can explain your observations.

Chapter XXI · What is the Nature of Current Electricity, and How is it used to do Work?

There was a time when it was believed that static electricity and current electricity were two different phenomena. Now it is believed that they are the same and that both are associated with electrons. In static electricity the electrons may be stored on a nonconducting body as a negative charge, or electrons may be removed from a nonconducting body, leaving a positive charge. As you have learned, electrons may be stored on rubber or removed from glass. They may be stored on metals, as in the electroscope, if the metal is carefully insulated from all conductors.

Static and current electricity are similar phenomena

In current electricity, however, the electrons are not stored, but flow along a conductor. When this flow of electrons is properly controlled, it may be made to furnish heat and light, bring about chemical changes of importance to industry, carry signals by means of telegraph and radio, and turn motors.

The properties of current electricity are not entirely new to you. From your study of the properties of metals you have learned how a current of electricity may be produced by chemical action. According to theory, electrons are released by chemical action between metals (zinc, for example) and acid or between metals and other chemicals. Do you remember how you used a magnet to discover the flow of electricity in a wire?

Set up an apparatus like that shown in Fig. 242. Keep the switch open, and dip the bare wire into the iron filings. Lift the wire. Has anything happened? Now close the switch, dip the wire into the filings again, and lift it out. When a current of electricity flows through it, the wire is like a magnet; for it will attract and hold iron filings.

Now if you open the switch again, you will see that the iron filings fall away from the wire. From your observations you can come to the conclusion that a wire carrying a current of electricity has magnetic properties, that is, properties of a magnet.

This phenomenon is important. "Why?" you may ask. Let us see.

A. What are Some of the Relations between Magnetism and Electricity?

The relations between magnetism (the property possessed by magnets) and electricity were studied during the early part of the nineteenth century by Joseph Henry in America and by Michael Faraday in England. An understanding of the relations has been extremely important in man's progress in the control of the natural forces around him. Through this understanding man has learned to make and to use electric motors and generators.

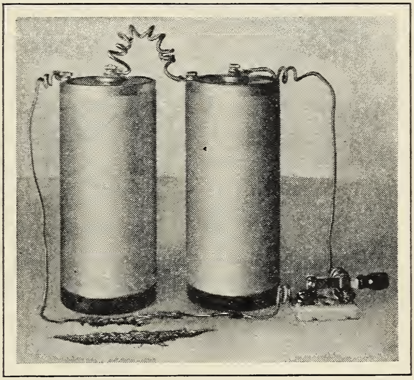


Fig. 242. When a Current of Electricity flows through a Bare Wire, the Wire is like a Magnet

Magnets are not new to you. You know that the most obvious property of a magnet is that it will pick up pieces of iron. When a magnet is brought near some small nails, for example, the nails are attracted toward the magnet and held to it. But have you ever noticed that while the nails will cling to either end of the magnet, they will not cling to the middle of it? The force of magnetism seems to be strongest at the ends of the bars.

There are only a few substances that show magnetic properties. Of these iron (or steel) is most familiar and most magnetic. Nickel and cobalt show some magnetic properties. Copper, zinc, and other common metals are classed as nonmagnetic. Nonmetallic substances, such as wood, wool, cotton, glass, and rubber, are nonmagnetic. They are not attracted by magnetic substances.

Some substances have magnetic properties; others have not

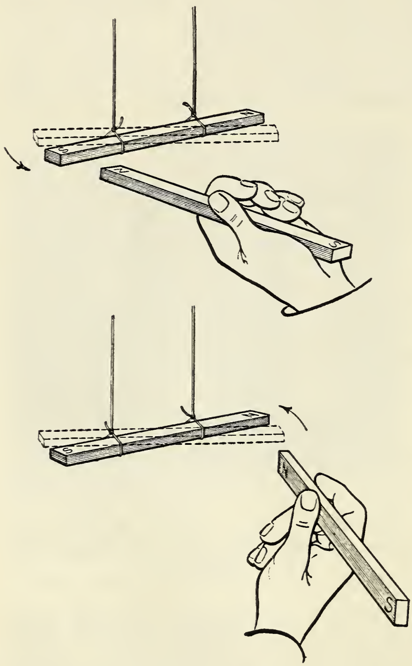


Fig. 243. Like Poles of a Magnet repel Each Other; Unlike Poles attract Each Other

To observe the action of one magnet on another you may use a bar magnet hung as shown in Fig. 243. Bring one end of a second bar magnet near to one end and then to the other end of the mounted magnet. Obviously, as shown in Fig. 243, one end of the mounted magnet is attracted and the other end is repelled by the second magnet. This observation furnishes convincing evidence that the two ends of a magnet do not have exactly the same properties, although both ends look alike and both ends will pick up nails.

Consider your observations a little more closely. A magnet mounted so as to swing freely is really a compass. Notice that the swinging bar in Fig. 244 comes to rest in a

north and south position. Because of this the end which points toward the north is called a north pole. The other end is a south pole. Look again at Fig. 243. The north poles of the bar magnets shown there are marked with an *N*. The south poles are marked with an *S*. Now study the relationship between these poles. Notice that the north pole of the magnet attracts the south pole and repels the north pole of a second magnet. In other words, like poles of magnets repel each other, and unlike poles attract each other.

Like poles of magnets repel; unlike poles attract

Should you like to make a magnet for yourself? The simplest way is to bring a bar of magnetized steel, one that has been made into a magnet, in contact with a bar of unmagnetized steel. In this manner you may magnetize the blade of your knife. Stroke the blade a few times over one of the poles of a bar magnet, and you find that the magnetized blade picks up small nails. A piece of soft iron (or of soft steel) also shows magnetic properties, but differs from the steel of your knife blade in that the soft iron does not hold magnetism after it is removed from the magnet. This property of soft iron may be illustrated as shown in Fig. 245. The nail (soft steel) will attract other nails or small tacks only while it is held by the bar magnet. The nail loses its magnetism immediately after it is removed from the hard-steel magnet.

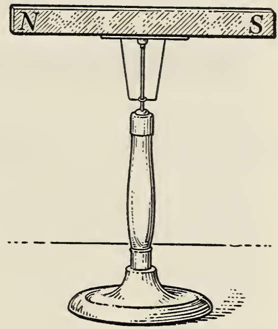


Fig. 244. A Magnet mounted so as to swing freely is really a Compass

The magnetic property of magnetized substances may be transferred to unmagnetized substances

A magnet of hard steel is called a permanent magnet; but of course it is not really permanent, for in the course of a long time it loses its magnetic properties.

The experience of magnetizing your knife blade may suggest to you the fact that you must take care of your watch while working with magnets. Why? The spring of your watch is made of hard steel. If the watch touches or even comes near a magnet, the hairspring may become magnetized. If this happens, you may be sure that the watch will not keep correct time. This is not serious, however, for it is a fairly simple matter to have the watch demagnetized, that is, make it lose its magnetism.

Fig. 245. A Piece of Soft Steel (a Nail, for Example) will not hold Magnetism after it is removed from a Magnet

The manner in which the forces are distributed about a magnet is shown at the top of Fig. 246. A piece of white paper has been placed over a bar magnet, and fine iron filings have been sprinkled on the paper. The paper is nonmagnetic, so it serves no purpose except to hold the filings. Notice the regular pattern that is formed. The little particles of iron seem to arrange themselves along lines which extend outward from the ends of the magnet. These lines, called lines of force, are curved and seem to join the two ends of the bar.

Now place two magnets under the paper so that unlike poles are near each other (the center diagram of Fig. 246). The arrangement of the particles of iron on the paper now suggests that lines of force continue from one magnet to the other. Let us try one more set-up. Arrange the magnets with like poles near each other, as shown in the bottom diagram of Fig. 246. Here the lines of force from the two magnets seem to

Magnetism shows lines of force

repel each other. After these observations it should be clear that like poles repel and unlike poles attract each other.

If you think that the paper plays a part in what you have seen, substitute a piece of window glass for the paper. Notice that the magnetic lines of force pass through glass just as readily as they pass through paper and that the pattern formed by iron filings on glass is similar to the pattern formed on paper. In the same way the lines of force pass through wood, copper, and zinc; in fact, they pass through any nonmagnetic substance. If you should use a sheet of iron, the effect would of course be different; for the sheet of iron is itself magnetized when brought near a magnet.

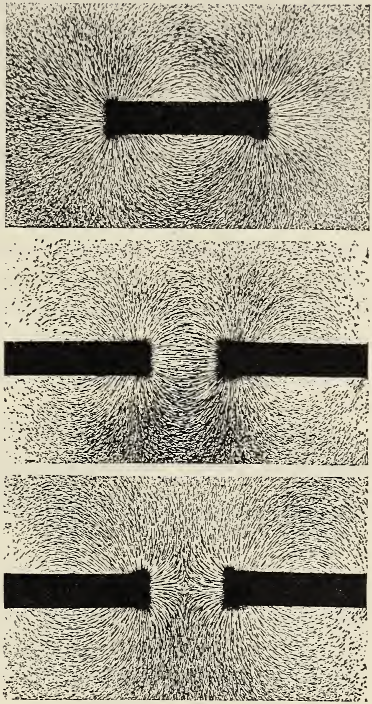


Fig. 246. Iron Filings scattered on a Piece of Glass or Paper which is placed over a Bar Magnet will demonstrate by the Lines of Force which are formed that Like Poles repel Each Other and Unlike Poles attract Each Other

Can you tell from the lines of force which are like poles and which are unlike poles of the magnet?

In order to explain the magnetic properties of iron a theory of magnetism based on the molecular theory has been proposed. The molecular theory, as you know, supposes that all matter is made up of molecules. In the case of gases there is much vacant space between the molecules, and the little particles

move freely. In the case of liquids there is not so much space between the molecules, and they move with less freedom. In the case of most solids the molecules are packed closely together. In general, then, it is supposed that the hardest solids are those in which the molecules move with least freedom. Thus molecules of iron in soft steel move with greater freedom than do molecules of iron in hard steel.

The molecular theory of magnetism is based upon the supposition that each molecule of a magnetic substance, such as iron, is a permanent magnet, whereas each molecule of a nonmagnetic substance, such as zinc, is not. If each molecule of iron in a steel bar is a magnet, the bar becomes a magnet when the molecules are arranged in the proper systematic fashion. Let us see if we can describe by means of this theory just what is thought to happen when an iron bar is magnetized.

Magnetism may be explained in terms of the molecular theory

Consider the arrangement of molecules in an unmagnetized iron bar. According to the molecular theory the molecules in this bar are arranged as shown in Fig. 247, *a*. Each molecule is a magnet, but there is no systematic arrangement. You can imagine lines of force between the individual molecules similar to those you saw for yourself in Fig. 246. This diagram should indicate too that, while the molecules themselves are magnets, the bar as a whole is not. Do you see why?

But what happens when this bar is magnetized? Study Fig. 247, *b*, closely. Here the north pole of a magnet is being pushed along the steel bar in the direction shown. According to the theory the molecules shift their position. At the right-hand side of the bar, over which the magnet has just passed, the molecules are arranged in a systematic fashion. The south poles of the molecules are being turned toward the north pole of the magnet as it is drawn along the bar. The magnet has not yet reached the left-hand end of the bar, and the molecules there have not as yet changed their

position. As the magnet is moved from right to left along the bar, lifted, and moved right to left again, time after time, all the molecules, according to the theory, become arranged in systematic fashion as shown in Fig. 247, *c*. Now we say that the bar is magnetized. Do you see how the molecular theory is used to explain magnetism?

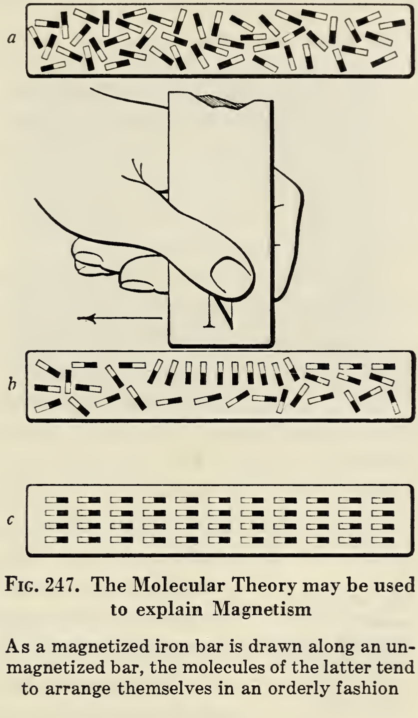


Fig. 247. The Molecular Theory may be used to explain Magnetism

As a magnetized iron bar is drawn along an unmagnetized bar, the molecules of the latter tend to arrange themselves in an orderly fashion

But why does a bar of hard steel become a permanent magnet? You remember we said that in a hard substance the molecules are packed together more tightly than in a soft substance. Thus the molecules in a bar of hard steel cannot move so freely. When once arranged, they tend to keep their arrangement. In terms of this theory, why is a bar of soft iron or of soft steel a temporary magnet? In the softer substance the molecules move more freely. Therefore they do not keep their systematic arrangement. From this we may explain why the hardest steel holds magnetism longest.

There are other observations that may be explained by this theory. Heating a bar magnet destroys its magnetism. This would be expected, for according to the molecular theory heat causes the molecules to move faster and with

greater freedom. As the molecules move, they lose their systematic arrangement.

Why cannot a bar of zinc or copper be magnetized? According to the theory the molecules of which they are composed are nonmagnetic.

B. How may the Action of a Compass be Explained?

The magnetic compass with which you are now familiar is not new. Its use in navigation has been recorded as early as the thirteenth century. Without its use Columbus might not have found the New World. Thus the compass has played a very important part in the whole story of exploration and discovery.

The earth itself possesses magnetic properties

The behavior of a compass indicates that the earth itself has magnetic properties. The directions toward which the needle of a compass points (Fig. 248) are called the north and south magnetic poles. Between these two points lines of force run over the surface of the earth, just as lines of force run between the poles of a magnet. A compass needle takes a position which is parallel to these lines of force.

The centers of magnetic force upon the earth are called the north and south magnetic poles

Notice that the *north* pole of a compass needle is attracted to the *north* magnetic pole, while the *south* pole points to the *south* magnetic pole. Obviously the north magnetic pole must have the properties of the south pole of a magnet, and the south magnetic pole the properties of the north pole of a magnet. This supposition would explain the action of the compass needle. Remember, then, that the use of the words *north* and *south* in connection with the magnetic poles refers to their location and not to their properties.

One other point should be made clear. The magnetic poles are not in the same positions as the poles of the earth's axis. For this reason the compass does not point true north

from every position on the surface of the earth. The magnetic pole of the Northern Hemisphere is located at 71 degrees north and longitude 96 degrees west. This point, shown in Fig. 249, is on a peninsula in the northern part of the district of Keewatin in Canada. It is near the meridian that passes through Winnipeg. The south magnetic pole, also shown in Fig. 249, is at latitude 73 degrees south and longitude 156 degrees east, on a meridian passing between Australia and New Zealand. From this you can see that the magnetic pole in northern Canada is about 1200 miles from the north pole. Thus an observer standing at the north pole of the earth's axis would find that the north pole of his compass needle would point south. Similarly an observer at the south pole of the earth's axis would find that the south pole of his compass needle or free-swinging magnet would point north.

Ewing Galloway

Fig. 248. A Compass is used to tell Direction

The directions toward which the needle of a compass points are called the north and south magnetic poles

If a compass needle points to the magnetic north, and this point is not the same as the geographic north, it is obvious that a compass needle does not always point to the true north. In fact, there are only a few positions in which it does. In other words, the compass needle is said to deviate, or turn, from a true north position. This turning, or deflection, varies at different points. In

The magnetic poles do not correspond in location with the geographic poles

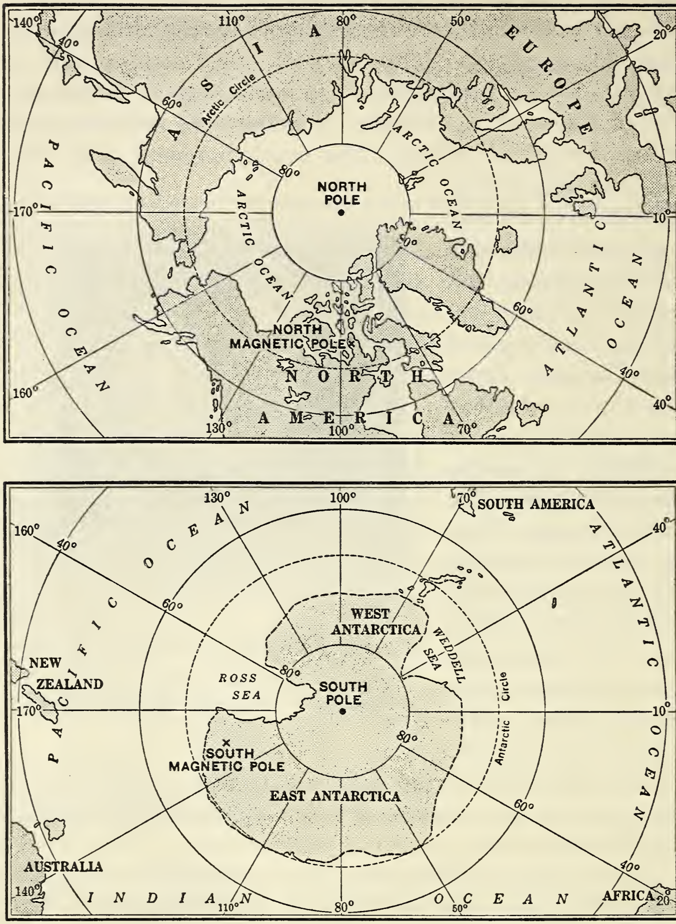


Fig. 249. The Magnetic Poles of the Earth are not in the Same Positions as the Poles of the Earth's Axis

For this reason a compass needle does not always point to true north. From a position in southern Greenland, what direction would a compass needle point? From a position at the south pole what direction would it point? Why is it important to know the location of the magnetic poles?

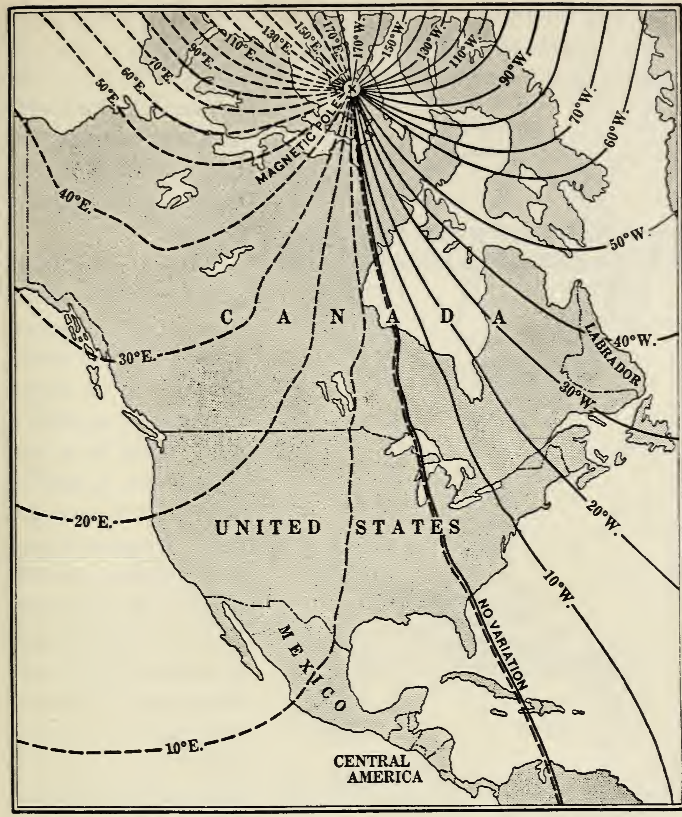


Fig. 250. Accurate Observations have made it Possible to map the Amount of Deflection from True North in Different Positions on the Continent of North America

Of what value do you think such a map as this would be to navigators?

Fig. 250, lines are drawn on a map, showing the amount of deflection from north in different positions on the continent of North America. In the state of Maine the compass needle points 20 degrees west of true north, and in the state of Washington it points 25 degrees east of true north.

It is only on a line marked 0 that the compass needle takes a true north-and-south position. How much is the deflection in the region where you live? The position of the magnetic poles slowly changes, so a map like the one in Fig. 250 must be continually revised.

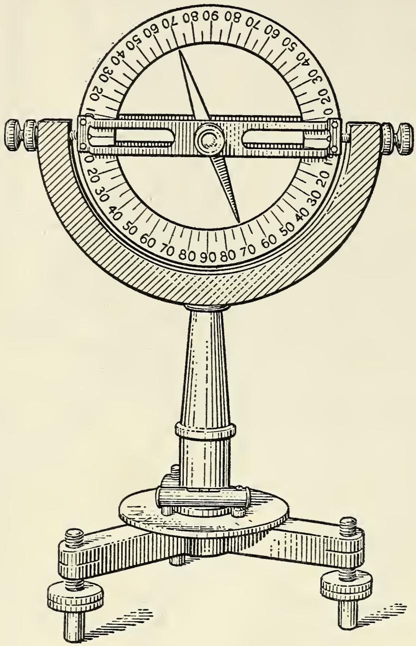


Fig. 251. A Dipping Needle illustrates the Dip of a Compass Needle toward the Magnetic Pole

What would be the position of the needle if this instrument were over a magnetic pole?

The dip of a compass needle is another interesting observation. If such a needle is mounted as shown in Fig. 251, so that it may swing in a vertical plane, it may be seen that it does not come to rest in a position tangent to the surface of the earth, that is, at right angles to a line drawn from the center of the earth to a point on its surface. The needle is attracted by the magnetic poles of the earth in just the same way that a compass needle is attracted by the poles of an ordinary magnet. In the Northern Hemisphere the needle dips toward the north magnetic pole.

The lines on the map in Fig. 252 show positions in which the dip of a compass needle is equal. At the latitude of Washington, D.C., and St. Louis the dip is about 70 degrees. Over the magnetic poles the dip is 90 degrees.

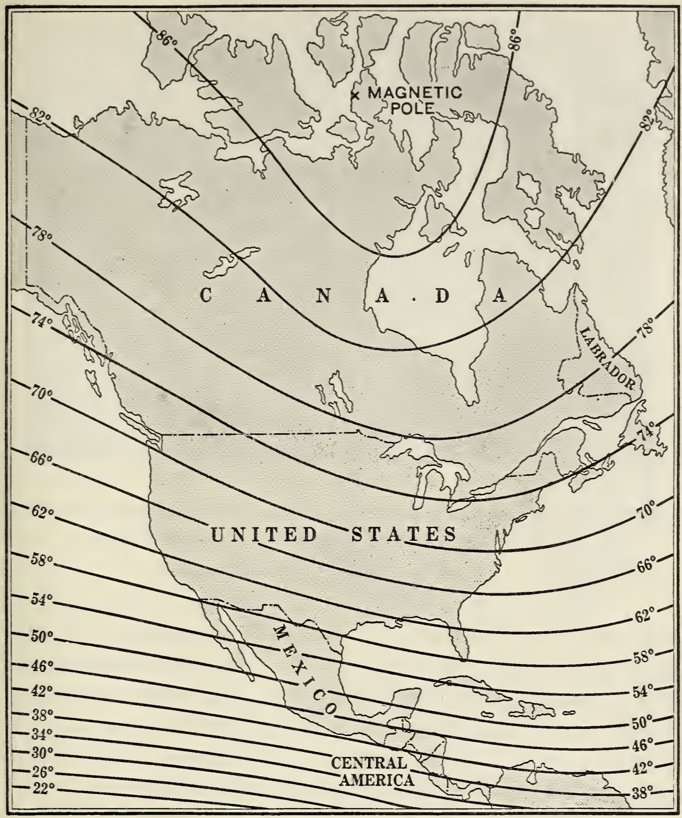
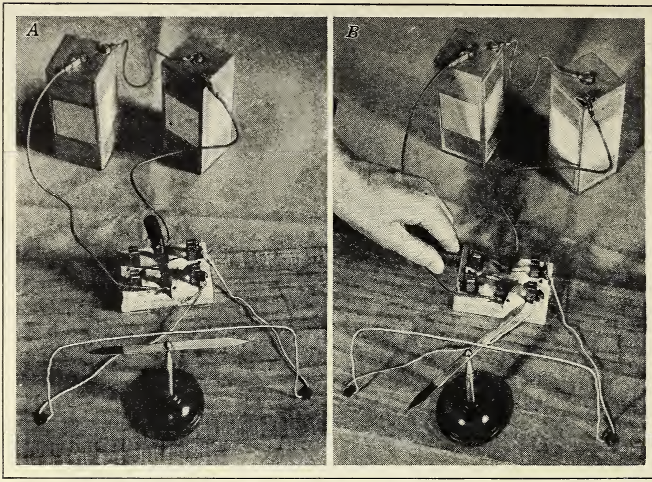


FIG. 252. The Dip of a Compass Needle is Not Equal at All Points on the Surface of the Earth

What is the dip where you live?

C. What is an Electromagnet?

Perhaps you are wondering now just what relationship magnets bear to the problem of current electricity. Only through the use of magnets may electrical energy be used to turn the wheels of industry. Stated in simple terms, a



Ewing Galloway

FIG. 253. The Magnetic Properties of a Wire are illustrated by the Effect on the Compass as a Current flows through the Wire

A, switch open; *B*, switch closed

wire carrying a current has magnetic properties. It loses these when the current is shut off. The application of this fact is found in electrical machinery, where the magnetism of wires carrying currents acts as an attracting force or as a repelling force. These forces may be applied to ring a bell, turn the wheels of a motor, and do other things.

Let us study the magnetic properties of a wire carrying a current. Fig. 253 shows two dry cells connected through a switch. The apparatus may be familiar to you, for you have already used one like it to find the flow of current in a wire. Turn back to Fig. 139 on page 252. One piece of wire, placed in a north and south direction, passes over a compass needle mounted on a stand. When the needle comes to rest (with the switch open), it is parallel to the wire. When the switch is closed, the needle will swing into a position that is at right angles to the wire. It swings back

into a position parallel to the wire when the switch is again opened. If you change the connections of the switch to the cells so that current flows through the wires in the opposite direction, then the direction in which the compass needle points will be reversed. It is obvious from these observations that the wire has magnetic properties. It is obvious too that it loses these magnetic properties as soon as the circuit is broken.

A wire through which an electric current is flowing possesses magnetic properties

There are other ways in which you may observe the magnetic properties of a wire carrying electricity. One length of wire attached to dry cells may be passed through a sheet of paper as shown in Fig. 254. If iron filings are sprinkled on the paper while the switch is closed, the particles of iron will take a circular arrangement about the wire. The lines of force seem to circle the wire. A small compass placed alongside the wire, as shown in Fig. 254, may be used to show that the wire has magnetic properties. Notice that the compass needle does not point toward the wire. It takes a position that is tangent to a circle drawn about the wire, in other words, at right angles to its diameter. With the compass in position as shown in Fig. 254 change the connections with the cells and cause current to flow through the wire in an opposite direction. How does the change affect the compass?

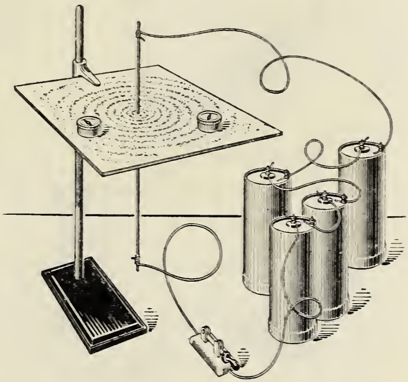


FIG. 254. The Magnetic Properties of a Wire through which a Current of Electricity is flowing may be shown by the Iron Filings around a Wire

Notice the position of the compass needles

A coil of wire shows the properties of a magnet even more strongly than does a single length of wire. When a small compass is placed near a coil of wire, as shown in Fig. 255, the compass needle, when the switch is closed, takes a position that is parallel to the length of the coil. If the connections to the cell are changed so that current flows through the coil in the opposite direction, the direction in which the needle of the compass points is reversed. Evidently the coil has properties similar to the properties of a steel magnet. By reading the compass you learn that one end of the coil is a north pole and the other end is a south pole. But since the needle of the compass changes direction when the direction of the current changes, it is evident that the poles change. This observation is important, as you will see a little later when you study the dynamo and the motor.

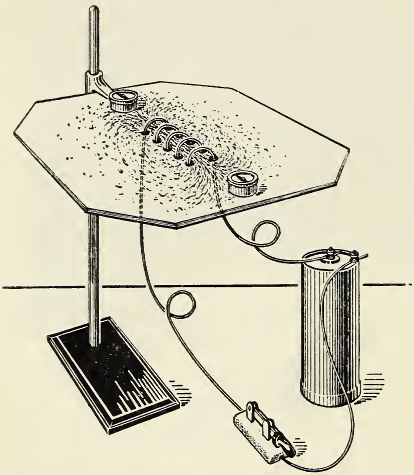


Fig. 255. A Coil of Wire carrying a Current shows the Properties of a Magnet even More Strongly than does a Single Length of Wire

Substances possessing magnetic properties due to a current of electricity are called electromagnets

Study the apparatus in Fig. 256. This shows a coil of wire wound about a large nail. When the switch is closed, the nail shows magnetic properties. It has a north pole and a south pole, and it will pick up objects made of iron. It seems that when this nail was placed inside the coil and the current was turned on, the lines of force observed in Fig. 255 passed through the iron

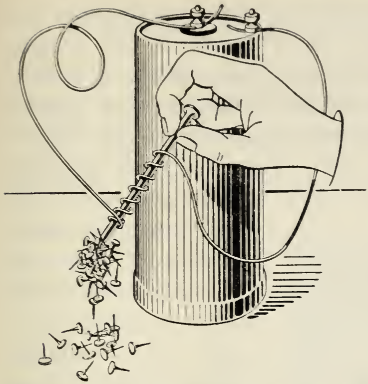


Fig. 256. An Electromagnet may be made by Placing a Nail inside a Coil of Wire through which Current is Flowing

nail, and this in turn became a magnet. You may test it, following the suggestions in Fig. 243. Notice that the magnet may be made stronger by winding more wire about it. Notice, too, that the nail, being of soft steel, loses its magnetism as soon as the switch is opened.

Here, then, is another type of magnet. Previously you made mag-

Keystone

Fig. 257. Powerful Electromagnets are used in Handling Objects made of Iron and Steel

The principle here is exactly the same as the one which produced the effects you saw in Fig. 256

nets by taking a piece of metal already magnetized and transferring its magnetism, so to speak, to an unmagnetized substance. But now you have made a magnet by passing a current of electricity through a wire. Such a magnet, called an electromagnet, is a magnet only while a current flows through the wire. Powerful electromagnets are used in handling objects made of iron and steel. The electromagnet shown in Fig. 257 is a bar of soft steel wound with many turns of wire. It is a magnet while current flows. When the current is cut off, it loses its magnetism and drops the load.

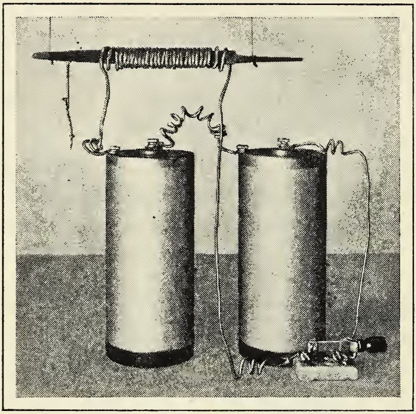


Fig. 258. A Permanent Magnet may be made by Placing a Piece of Hard Steel inside a Coil of Wire carrying a Current

Perhaps your observations of this electromagnet may suggest a way for making a permanent magnet. Place a bar of hard steel (a file, for example) inside a coil of wire, as shown in Fig. 258. There are many turns of insulated wire in this coil. The wire is joined to two dry cells through a switch. Notice that when the switch is closed, the file has strong magnetic properties. Evidently lines of force flow through the file. From your study of Fig. 247 you may suppose that the molecules of iron in the steel have arranged themselves in a systematic fashion. Do you see why? It is interesting to observe that you can make a better magnet if, while the current is running, you tap the file gently with a hammer. The jarring seems to assist in getting the molecules into the proper arrangement.

But now let us apply what you have learned.

D. What causes an Electric Bell to Ring?

One of the simplest mechanisms for changing electrical energy into energy of motion is an electric bell. In this instrument energy is changed through the use of an electromagnet. Perhaps you have at some time taken the cover off an electric bell. If so, Fig. 259 should be familiar to you. Notice the two coils of wire, each wound around a core of soft steel. Notice, too, that each core is fastened firmly at one end to a bar of soft steel called a yoke. With this arrangement the free end of each core is a pole of a U-shaped magnet. The winding of the magnet itself is as it would be if you were to wind the wire on the two ends of a straight bar and then bend the bar as shown in Fig. 260. The clapper is so attached to a piece of metal, called an armature, that it may move back and forth. This armature, like the cores of the magnet, is made of soft steel. When no current is flowing, it is held away from the poles of the magnet by a spring. A spring holds the armature firmly against a contact screw.

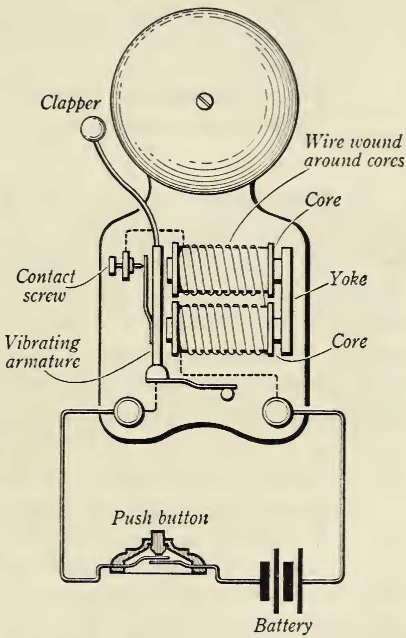


FIG. 259. An Electric Bell rings because of the Rapid Magnetizing and Demagnetizing of Electromagnets

Can you trace the electric circuit through this bell?

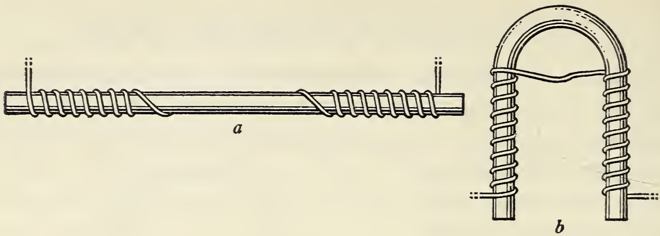


FIG. 260. Do you know how to wind an Electromagnet?

Notice that the straight bar, *a*, is wound and that the bar is then bent, as in *b*

To demonstrate how the bell works, connect it with a dry cell and push the button. What happens? Yes, the bell rings; but what is the explanation? According to the electron theory, when you push the button a stream of electrons flows toward the coils from the binding post attached to the zinc plate. From the coils the electrons flow toward the contact screw, and from the contact screw toward the carbon plate in the center of the cell. There is, then, a steady flow of electrons from one post of the cell, through the bell itself, and back to the cell.

An electric bell rings owing to the rapid magnetizing and demagnetizing of electromagnets

As soon as the circuit is closed by pushing the button, the coils become an electromagnet. But immediately the magnetic force pulls the bar away from the contact screw, and the circuit is broken. The soft-steel cores of the electromagnet lose their magnetism when the circuit is broken, and the spring pushes the bar back against the contact screw. Again the circuit is closed, again the bar is attracted toward the magnet, and again the contact is made and broken. Each time the bar is pulled toward the magnet the clapper strikes the bell. This making and breaking of the circuit continues as long as the circuit through the push button is kept closed. The vibrating armature is obviously an automatic mechanism for making and breaking an electric circuit. If you will

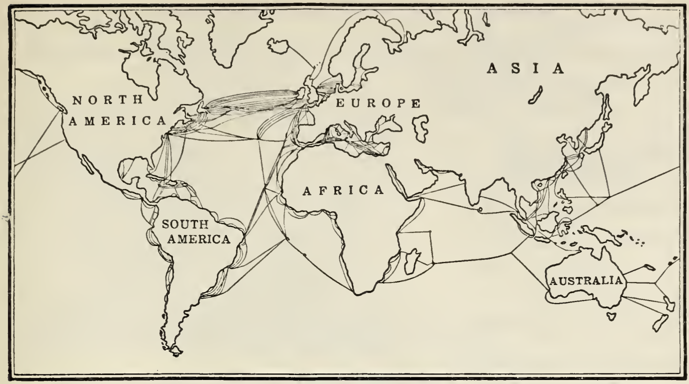


FIG. 261. Today the Cable and the Telegraph are Important Means of Communication

For lack of space it is impossible to indicate all lines or all radio stations

follow this circuit through the diagram in Fig. 259, you will see that, while the bell is ringing, the soft-steel cores are magnetized and demagnetized at the rate of many hundred times per minute.

E. How does a Telegraph Instrument Work?

The first telegraph line was built in 1844 between Baltimore and Washington, a distance of 40 miles, from directions furnished by Samuel F. B. Morse. Seven years later a line from Washington to St. Louis, a distance of 1000 miles, was completed. This was considered a great achievement. Yet as a comparison there were in 1927 over 2,000,000 miles of telegraph wire in the United States. During that year 215,000,000 telegrams were sent.

A few years after the first telegraph line was built, telegraph cables were laid across the ocean. These cables consist of a copper wire wrapped with steel wire and rubber to protect and insulate it. The first successful cable was laid between Dover in England and Calais in France in 1851.

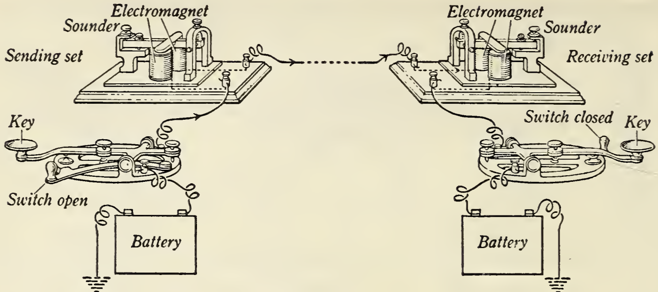


FIG. 262. In a Telegraph Circuit the Principles of the Electromagnet are applied to the Key and Sounder

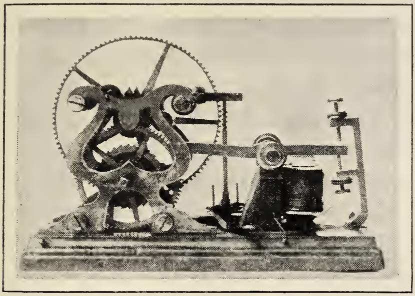
Trace the operation of this circuit from the description in the text

The first cable across the Atlantic was laid in 1865. There are nearly 400,000 miles of ocean cables in use today, as shown in Fig. 261. The charges for the use of the first cable were about $100 for each message. The present rate is about 25 cents per word.

The tremendous growth of the telegraph and cable really depends upon an increasingly efficient application of the principles of the electromagnet, which you have just studied. A telegraph key and sounder is in some ways like an electric bell. In its simplest form the sounder is an electromagnet with an armature mounted over it. When a key is pressed to close the circuit, current may flow through the coils of the magnet. The magnetic force draws the armature attached to a metal rocker arm toward the poles of the magnet. Study the circuit in Fig. 262. When the armature is pulled downward toward the magnet, one end of the rocker arm strikes another piece of metal, causing a sharp click. When the key is released, the circuit is broken. The electromagnet now loses its magnetism, and the spring pulls the armature away from the poles of the magnet. This causes the end of the rocker arm to strike the

An electromagnet is a necessary part of a telegraph instrument

metal above it. Again a click is produced. A short interval between the clicks of the arm, as the armature moves down and up, produces the effect called a dot. If there is a longer interval between the clicks, a dash is made. A trained telegrapher knows that dot-dash (- —) is the letter *A*. There are other combinations of dots and dashes to make the other letters.

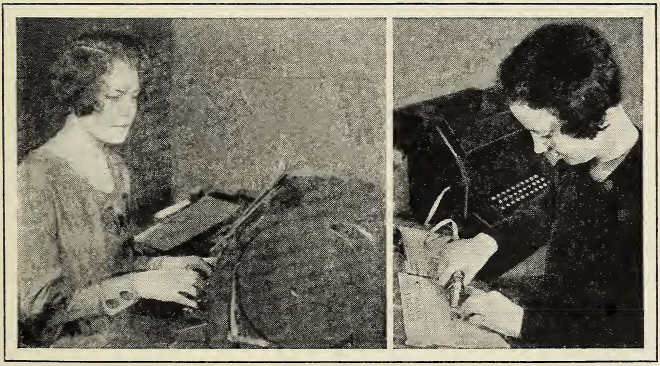


International Newsreel

Fig. 263. The First Telegraph Instrument was a Crude Affair

The model of Morse's first instrument

The first sending and receiving instruments (Fig. 263) were crude affairs compared with those in use today. The dot-dash instruments are now largely replaced by the teletype machines illustrated in Fig. 264.



Western Union

Fig. 264. The Modern Telegraph Instrument is a Highly Complex Instrument using Many Electromagnets

As the message is typed on the sending instrument at the left, electromagnets cause the corresponding letter keys to strike a tape on the receiving end. At the right a clerk is shown pasting the printed tape on the telegraph blank

The message to be sent is typed on one of these machines. This process of typing operates a similar machine, having a keyboard like a typewriter, in the station to which the message is sent. As copy is typed in the sending station a duplicate copy is automatically typed on a strip of paper tape in the receiving station. In this way two operators, many miles apart, can type messages back and forth, each one seeing, as fast as it is typed, what the other writes. Although much more complex than the simple telegraph sounder, these machines also operate by means of electromagnets. Each key on the receiving typewriter is operated by a separate electromagnet. When the proper circuit is closed by the key on the sending end, the key on the receiving typewriter is operated by the electromagnet and prints that particular letter. Such machines make it possible to send and receive messages at a speed much greater than that of even the most expert telegrapher.

Teletype instruments may be made to set type for printing newspapers. It is now possible to type news on a teletype machine in New York City and have it set up, as it is typed, for printing in newspapers in England.

F. How is an Electromagnet used to turn the Armature of a Motor?

Of all the mechanisms run by electrical energy the electric motor is probably the most important in our modern civilization. Consider its many uses. It operates the time-saving equipment of the modern housewife; it is responsible, too, for much of the modern high-speed machinery which plays so important a part in the industry of today. As you look at a commercial motor, you may be struck by its seemingly complex nature. It is a complex mechanism. Yet the principles which explain its operation are fairly simple and may easily be demonstrated by some simple laboratory experiments.

The motor is another application of the electromagnet. At least one of the magnets in any motor must be an electromagnet. In small demonstration motors a pair of permanent magnets may be used with one electromagnet. In commercial motors, however, only electromagnets are used. Let us study a small demonstration motor like the one shown in Fig. 265. Let us learn the essential parts of it and the purposes for which each part is used. In this motor the *field magnets* are made of hard steel. They are therefore permanent magnets. Between the poles of the field magnets is the armature. This is an electromagnet. It consists essentially of wire wound about a core of soft steel. The armature is mounted so that it may turn on a shaft. Surrounding the shaft is the commutator. Notice that it is made in two parts and that these parts do not touch each other. There are also two metal strips, called brushes, that rub against the commutator as it turns.

An electromagnet is a necessary part of an electric motor

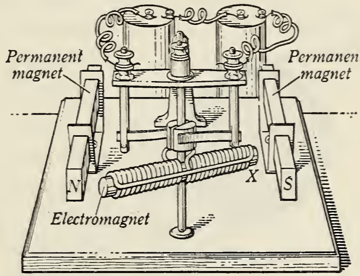


FIG. 265. The Motor is Another Application of the Electromagnet

The principle of a motor may be demonstrated in this simple model. What are the essential parts of a motor?

As you examine the wiring on the armature (shown in Fig. 265), you see that one end of the wire is attached to one part of the commutator, the other end of the wire to the other part. Now follow the wire from the commutator toward the end of the electromagnet that is marked X. Notice that the wire is continuous from one end of the magnet to the other end. If you follow it, you see that this wire is finally joined to the other part of the commutator.

The armature becomes an electromagnet as current flows through the coil of wire

Now follow the current from the cells through the armature. Think of the electrons entering through one side of the commutator, flowing through the coils, and leaving through the other side of the commutator. The two parts of the commutator are insulated from each other, as shown in Fig. 266. Electrons, then, reach the coil through one part of the commutator and leave through the other part. You must follow closely the lines in the diagram to see this.

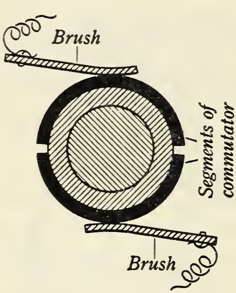


FIG. 266. Notice that the Two Parts of a Commutator are insulated from Each Other

Why is this necessary?

Now test the magnetism of the armature. Remove the field magnets but leave the dry cells attached to the binding posts, as shown in Fig. 267. Of course the armature does not turn without the field magnets. Bring a compass needle near one pole of the magnet, as shown in Fig. 267, *a*, and determine which is the north and which the south pole. Mark the north pole with a piece of chalk. With your hand turn the armature half a turn to the position shown in Fig. 267, *b*. Does the north pole remain the north pole? You see that it does not. The poles reverse as the armature turns. The circuit is such that electrons may flow from the zinc plate of the cell through the brush to one part of the commutator. From here the circuit continues through the coil to the other part of the commutator. The parts of the commutator are separated so that electrons cannot pass directly from one to the other. Therefore the electrons must pass through the coil. From the second part of the commutator the circuit continues through the brush to the carbon plate of the cell.

The poles of the electromagnet reverse as the armature turns

With the armature in the position of Fig. 267, *a*, the north pole is at the right-hand side of the page. Arrows indicate the direction of electron flow through the coil.

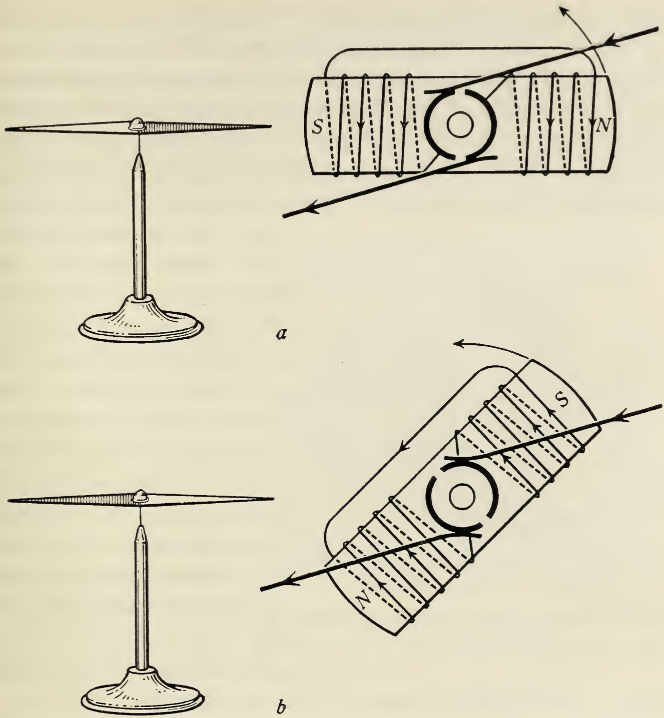


FIG. 267. The Poles of the Electromagnet in the Motor reverse as the Armature Turns

When the armature is moved, the brushes each make contact with the other part of the commutator. Now the electrons must pass through the coil in a direction which is opposite to the direction in which they flowed in the first case. As the direction of flow changes, the poles of the magnet reverse. The *N* pole of Fig. 267, *a*, is the *S* pole of Fig. 267, *b*. The poles reverse every time the brushes slip from one part of the commutator to the other.

Now replace the field magnets and start the motor running. You recall that unlike magnetic poles attract and

that like poles repel each other. The armature is mounted so that it turns in the same direction as the hands of a clock. In Fig. 267 a south pole of the armature is approaching a north pole of the field magnets, and a north pole of the armature is approaching a south pole of the field magnets. Thus the poles of the field magnet are attracting the poles of the armature. But just as the poles are all in line, the brushes slip to the other parts of the commutator as shown in Fig. 267, *a*, and Fig. 267, *b*, and the poles of the armature reverse. The south pole becomes a north pole, and the north pole becomes a south pole. Now there is repelling force between the poles of the armature and the poles of the field magnet. As the result of these attracting and repelling forces the armature turns round and round.

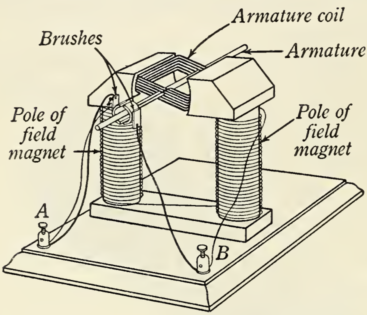


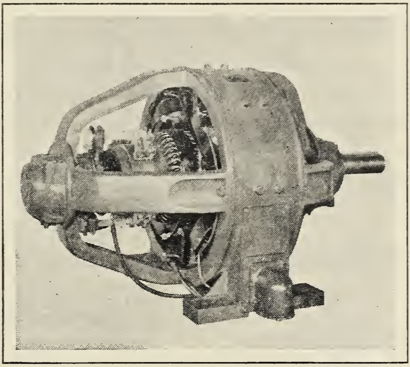
Fig. 268. In Most Motors the Field Magnet is an Electromagnet

Can you trace the flow of current through this simple motor?

Perhaps you have a demonstration motor in which the field magnet is an electromagnet. A diagram of such a motor is shown in Fig. 268. A piece of wire is wound about the electromagnet. The ends of the wire are attached to the binding posts at *A* and *B*. The ends of the armature wire are connected, through the brushes, to these same posts. When the circuit is closed, electrons flow through the field coil and through the armature coil, making the field magnet an electromagnet. The field coil is of fine wire, and there are many turns of it. The armature coil is of coarser wire, and there are fewer turns of it. The coarser wire of the armature offers less resistance to the flow of current, and more current passes through it than through the field coil.

The flow of current makes both coils magnetic. The direction of flow of electrons through the field coil does not change while the motor is running, so the poles of the field magnet do not reverse. The poles of the armature, however, reverse with each revolution, regardless of whether the field magnet is an electromagnet or a permanent magnet.

A demonstration motor like the one you have just examined would not be very satisfactory for the electric sweeper or for any other practical use. It is obvious that such a motor could not exert much force. A motor with four field poles and four poles on the armature would run more smoothly and with more efficiency than a motor with but two poles. Such a motor is shown in Fig. 269. There are as many parts in the commutator as there are poles on the armature. Commercial motors work on the same principle, but they are more complex in that they have more poles.



General Electric

Fig. 269. A Motor with Four Field Poles and Four Poles on the Commutator runs more smoothly than a Motor with Two Poles

Can you explain why?

Small motors are used for many purposes. They sweep the floor, wash the clothes, and run the sewing machines. Larger motors run street cars, electric trains, and heavy machinery. Thus electrical energy is used to do work in place of muscular energy.

Each of these mechanisms — the electric bell, the telegraph, and the motor — may be operated with electrical energy that has been carried over wires for long distances. The power house from which energy comes may be many

miles from the machinery in which the energy is used. Electricity is of great importance in the life of today because it may be carried conveniently over wires to the place where it is needed. Through the use of electromagnets electricity may be changed easily to other forms of energy and used to do work.

Current electricity is a flow of electrons along a conductor. Certain substances possess magnetic properties. A wire carrying a current of electricity has magnetic properties. An electromagnet is a core of soft iron or soft steel wound about with a wire carrying an electric current. The electromagnet is an essential part of many common instruments, such as the electric bell, the telegraph, and the electric motor.

Can You Answer these Questions?

1. How may the action of a magnet be explained? Why do some substances form permanent magnets while others do not?

2. What is meant by lines of force?

3. What is meant by the deflection of a magnetic needle? by the dip? Of what importance are these phenomena in navigation?

4. What are the differences between an electromagnet and a bar magnet? How may these differences be explained?

5. What are the essential parts of an electric bell, and how do they function in causing the bell to ring?

6. What part do the principles of magnetism play in a telegraph circuit?

7. Why is the armature magnet in a motor an electromagnet?

8. Why is it important that the two parts of the commutator should not be connected to each other?

9. What is meant by the statement that the polarity of the armature changes as this part turns? Of what importance is this in the proper operation of the motor?

10. Of what use are the brushes?

Questions for Discussion

1. If you joined the two ends of a bar magnet with a piece of wire, would this wire too have the properties of a magnet?

2. Why should the magnetizing of a watch have any effect upon its proper time-keeping?

3. Why do you think the lines of deflection and dip in Figs. 251 and 252 are wavy and not straight?

4. Why should the direction of flow of electric current through a wire affect the direction of a compass needle?

5. You may have heard electric bells in which the hammer gives just one loud stroke instead of ringing steadily. What changes should be made in the bell in Fig. 259 to make this possible?

6. Why should a motor with four field poles and an equal number of poles on the armature run more smoothly and with more efficiency than one with but two poles?

Here are Some Things You May Want to Do

1. Set up a telegraph line between your house and a neighbor's.

2. Faraday and Henry, one in England and the other in America, discovered nearly the same things at the same time. See how many other examples you can find where two inventors, discoverers, or explorers found the same or nearly the same things at nearly the same time. Another example would be that of Scott and Amundsen, who reached the south pole only a short time apart.

3. Read the statements along the sides of the pages in this chapter and decide which you can test out for yourself through simple laboratory experiments. Try your experiments, and build a report on some such form as the following:

Principle	Experiments which I tried	Conclusions

4. Write a short biography, similar to those in this book, of Henry, Morse, or Field.

Chapter XXII · How is Electrical Energy generated from Coal and Falling Water?

Think through the events of a modern day if you will, and list some in which electricity plays a part. This list is easy to make if you live in a city, for electricity is your constant servant from the time you rise in the morning until the time you go to bed at night. If you live in the country, perhaps it is a little more difficult to do. Yet consider the radio, the telephone, the newspaper, the automobile, the railroad, — all the things which make your life so different from that of your grandparents.

Suppose someone asked you, "Where does that electricity come from?" You might answer, "From the power house in town," or "From the hydroelectric station down the river." "But," the person who asked the question might say, "that's not the answer I want. How does the power house or the hydroelectric station generate this electricity?" That seems a very difficult question, doesn't it? And so it is if you attempt to follow the process through the very complex masses of machinery which you find in such an electric plant. But if you will confine your answer to a statement of the principles which govern the operation of the electric generator, you will find that the question is not so difficult after all.

Recall some of the things you already know. You have learned that (1) electricity may be produced by chemical action, (2) a wire carrying a current shows magnetic properties, and (3) electromagnetism may be controlled and used to run motors.

Electricity is energy in one of its most easily usable forms. Energy in the form of electricity is essential to the operation of many kinds of machinery. Automobiles, airplanes, railway equipment, and home appliances include electrical devices.

A. How does a Simple Generator Work?

Do you remember how, a short time ago, you found that a piece of iron or steel is magnetized when placed inside a coil of wire that is carrying an electric current? Turn back to Fig. 256 if you wish and refresh your memory. But what do you think would happen if the conditions were reversed? Suppose you try it.

The principle of magnetism is used in the generating of electricity

Attach the terminals of a coil of wire to a sensitive galvanometer, which as you know is an instrument for revealing flow of current. Thrust a bar magnet into the coil, as illustrated in Fig. 270. Notice the needle of the galvanometer. Now with a quick motion remove the magnet from the coil. Again observe the needle of the galvanometer. Did you notice any difference in the movement of the needle as the bar magnet was pushed into the coil and back again? If you observed the galvanometer closely, you saw that the needle swung in one direction as the magnet was thrust into the coil, and in the opposite direction as the magnet was removed from the coil. What explanation is there for this? Evidently there is a flow of electricity through the coil. The magnet seems to cause a flow of electrons in one direction when the magnet is moved into the coil,

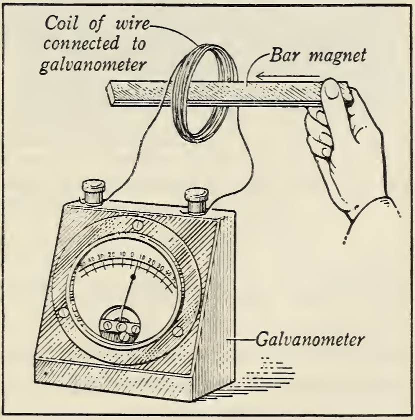


Fig. 270. The Principle of Magnetism is used in the Generating of Electricity

Do you know why the galvanometer registers an electric current in this experiment?

and in the opposite direction when the magnet is removed. The back-and-forth motion of the magnet causes electrons to move back and forth in the wire.

Let us try another experiment. Attach a small motor such as the one used in Chapter XXI to the galvanometer, as shown in Fig. 271. Spin the armature of the motor with

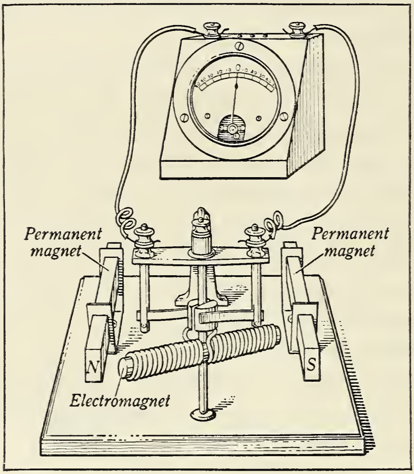


FIG. 271. This Simple Motor acts as a Generator when the Electromagnet is turned between the Poles of the Field Magnet

Is the principle here the same as that shown in Fig. 270?

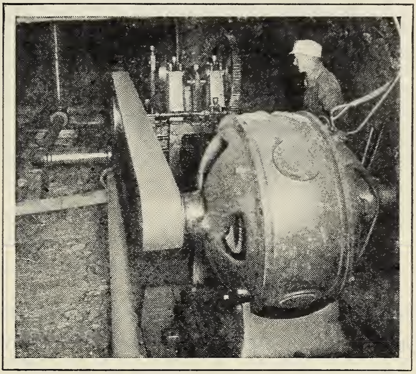
your finger and observe the galvanometer. Notice that a current of electricity is flowing through the galvanometer while the armature is turning. Once again you have generated a small amount of electricity, this time using a simple motor as a generator.

What is the origin of this electric current? Study Fig. 265 a little more closely. This simple generator has a pair of permanent magnets which together form what is called the field magnet. There is an armature, which is a bar of iron wrapped with wire. The terminals of the coil are attached to the parts of the commutator. These

parts are in contact with brushes; wires lead from the brushes to the binding posts, and from there to the galvanometer. Now use your imagination and picture a magnetic field between the bar magnets in Fig. 271. Do you see it? If you do, you see that what you really did with the simple generator was to spin the armature in a magnetic field. This is what caused the flow of electricity.

In a generator there is a magnetic field between the field magnets

The principle illustrated here is the same as the principle which governs the generation of electricity for lighting streets and homes. From its application you should be able to answer the question of what is an electric generator. In simplest terms it is a machine built so that forces may be applied to move a coil of wire within a magnetic field, as in the case of your generator, or, what amounts to the same thing, to move a magnetic field within a coil of wire, as illustrated by the simple experiment with the bar magnet.



Ewing Galloway

FIG. 272. The Principle of the Commercial Generator shown here is the Same as that of the Demonstration Generator which you observed in Fig. 271

The chief differences are (1) that the magnetic field is more powerful and (2) that the shaft is turned by mechanical power

The small generator used in your experiment produces current, but it does not produce very much. The magnets are not powerful, and on account of the manner in which the generator is constructed only a small force can be applied to turn the armature. But suppose the magnetic field were more powerful. Suppose the shaft were turned by a driving belt from a steam engine, as shown

in Fig. 272. Obviously a more powerful current would come from such a dynamo.

But remember that even the large dynamos that supply electricity for lighting homes and streets work on the principle that you have just found. The difference in results is one of size and quantity. There are many coils of wire on the shaft that turns inside the dynamo in the power station. There is a strong magnetic field about the shaft. When the shaft turns, therefore, the coils of wire cut many magnetic lines of force. Energy from the rotating magnets causes electrons to move in the wires. This energy of electrons driven along by the rotating magnets lights homes and streets, and runs electrical machinery.

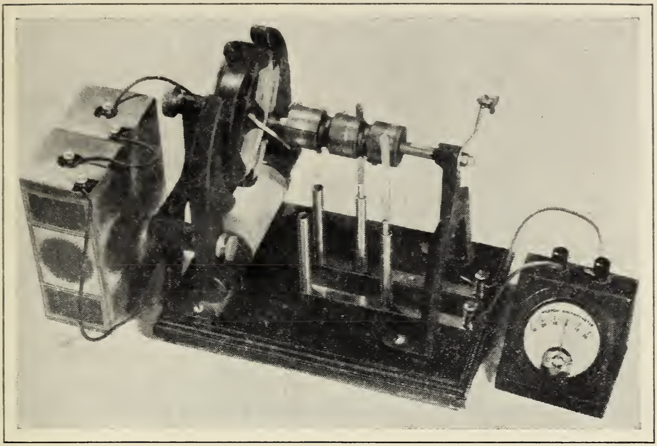
The electricity from a generator is thought of as a flow of electrons driven along by rotating a coil of wire in a magnetic field

B. What is an Alternating-Current Generator?

You have seen electricity generated. But how is it led away from the generator? To answer this question we shall have to experiment some more. In your science laboratory you may find a generator like the one in Fig. 273. Notice that the field magnet is an electromagnet. Notice, too, that a coil of wire is so mounted on the shaft that it may be turned within the magnetic field. If you follow the ends of the wires making up this coil, you will find that one of them is attached to one metal ring mounted on the shaft, and the other to another metal ring.

Brass strips, called brushes, are so mounted that they press against the metal rings. Wires leading to the galvanometer are joined through the binding posts to the brushes.

Now turn the coil by means of the handle, and watch the needle of the galvanometer. Notice that during one part of a turn the needle swings to the right, and during another part of the turn it swings to the left. This obser-



Ewing Galloway

FIG. 273. In an Alternating-Current Generator the Current flows first in One Direction and then in the Other

How does this set-up differ from that in Fig. 276?

vation is familiar to you, for you saw the same thing when you pushed a bar magnet into a coil of wire and then removed it. As a result you can decide that as the coil is turned between the poles of the field magnet, electrons flow back and forth through the wire. Since the wire forms a continuous circuit through the galvanometer, the needle swings back and forth as the coil is turned round and round. A machine which operates on this principle is called an alternating-current generator.

In an alternating-current generator the current flows first in one direction and then in the other

Why? Because the direction of current flow alternates, or flows first in one direction and then in the other. Why does the current alternate? Study the diagrams in Fig. 274, *a* and *b*. As the coil turns to the position shown in Fig. 274, *a*, it is cutting the greatest number of lines of force. In this position there is the greatest flow of current. In Fig. 274, *b*,

The greatest flow of current is induced when the armature cuts through the greatest number of lines of force

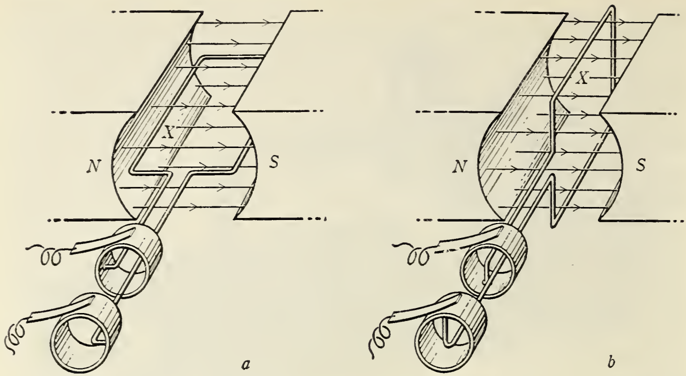


Fig. 274. **Current is Greatest as Coil moves through Position shown in *a*. The Direction of Flow changes as Coil moves through Position shown in *b***

the coil is cutting the smallest number of lines of force. Therefore the smallest amount of current is flowing. As you follow the coil through a half-turn, then, the amount of current changes from least to greatest and back to least. Through the next half-turn it changes in the same way.

Now follow the position of the wire marked with the letter *X*. Through one half-turn this section of the wire is cutting in one direction, say downward; through the other half-turn it is cutting in the opposite direction. As it moves from one half-turn to the next, the direction in which it cuts the lines of force changes. At the same time, as you have seen, the direction of current flow changes.

C. What is a Direct-Current Generator?

There are two types of generators, A.C. and D.C.

Perhaps you have seen the label "A.C. or D.C." on an electrical instrument. Perhaps you have seen a caution: "Use only on A.C. circuits." Evidently there are two types of current. But what does *D.C.* mean? It is an abbreviation for *Direct Current,* just as *A.C.* is an abbreviation for *Alternating Current.* What is the difference between them?

Fig. 275. Michael Faraday, *a Famous Pioneer in the Development of this Age of Electricity (1791–1867)*

A young bookbinder, given a ticket to a scientific lecture, sitting attentively before the great Sir Humphry Davy in the crowded auditorium of the Royal Institution,—who would guess that this uneducated boy was to become perhaps the greatest original experimenter the world has ever known? · Davy was the most prominent chemist in England. Faraday had had little schooling; but he had read some books on chemistry, and he knew what he wanted. He wrote to Davy and asked for a job. He got one as laboratory bottle-washer. The story goes that Davy soon realized he had made his greatest discovery; he had found Faraday · Faraday's early work was in chemistry, but he soon became interested in electricity and magnetism. Oersted had discovered that a current flowing through a wire will deflect a compass needle. There must be, then, some connection between magnetism and electricity. Faraday reasoned that if electricity can produce an effect on a magnetic needle, then a magnet might be made to produce a current of electricity. He experimented by pushing a magnet into a coil of wire, and got an electric current. He made the first dynamo. This invention made possible the extensive use of electricity and the easy means of changing electricity into other forms of energy · Faraday refused to accept a knighthood for his achievements. Neither he nor his wife cared for fame. He refused to become a commercial expert and adviser because it would leave him no time to experiment. Head of the Royal Institution for nearly forty years, his chief recreation was giving Saturday-morning lectures to children. Today in his memory the most prominent English scientists still carry on these lectures.

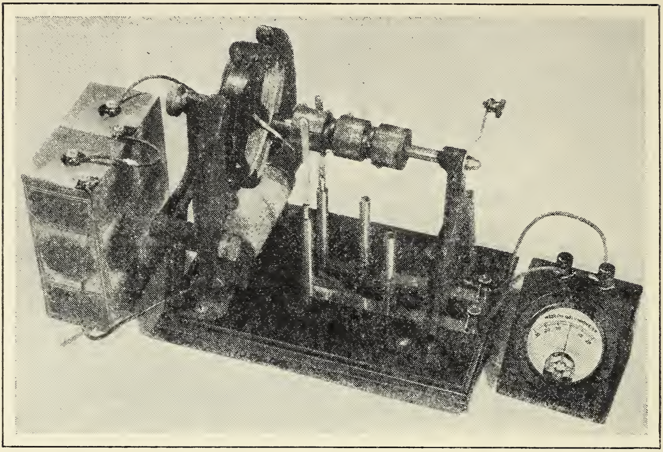


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FIG. 276. How does the Position of the Brushes in this Direct-Current Demonstration differ from the Set-up in Fig. 273?

Is the commutator different?

Now set the brushes of your simple generator as shown in Fig. 276. Notice that the brushes are now shown in contact with the split ring of a commutator. Study the diagram in Fig. 276. As you can see, there are two parts in the ring. One end of the armature coil is joined to one part, the other end to the other part. If you will turn the shaft, you will notice that the brushes slip from one part to the other. Observe the needle of the galvanometer. It swings in only one direction. Why should this be? Does the difference in the position of the brushes affect the current? Let us see.

In a direct-current generator the current flows in a continuous circuit, in one direction

In this generator the coil itself, as it rotates, cuts through the magnetic field in exactly the same way as it did in the alternating-current generator. Thus electrons flow back and forth in the coil just as before, moving in one direction during one part of the turn, and in another direction during another part of the turn. But what happens to them when they enter the wire? Imagine them moving, in

the wire, through one part of the ring into the brush, from there to the galvanometer, and then back to the coil through the other part. Notice that you have a complete circuit. Now turn the coil very slowly. Imagine that the galvanometer needle swings to the right. Keep turning the coil. The needle moves back toward the center of the dial. But just as it is back at the center, the brushes slip from one part of the ring to the other. Now while electrons flow in the opposite direction through the coil, they still move in the same direction through the galvanometer. Thus the needle swings again in the same direction as before. As the shaft is turned, then, the needle swings from the center of the dial but always in the same direction. There is a pulsating, or throbbing, current, of course, but it always flows in the same direction through the galvanometer. When the crank is turned rapidly, the pulsations, or beats, come so close together that the current seems to be continuous. Perhaps a study of the diagram in Fig. 277 will make this clearer. Can you follow the flow of electrons through this diagram?

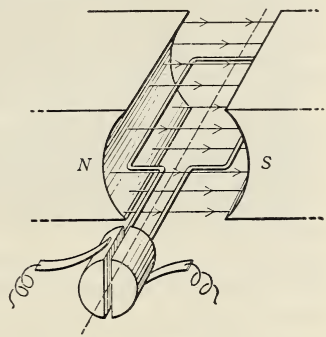


FIG. 277. In a Direct-Current Generator the Current flows as a Pulsating Current in One Direction

The current commonly supplied for houses and streets is alternating. It is satisfactory, and indeed more desirable than direct current, for most purposes. There are some industrial purposes, however, for which direct current must be used, such as in charging storage batteries, in electroplating, and in electrolysis. You may learn more about these processes at a later time. Battery current is always direct current. For certain purposes direct current must be changed to alternating.

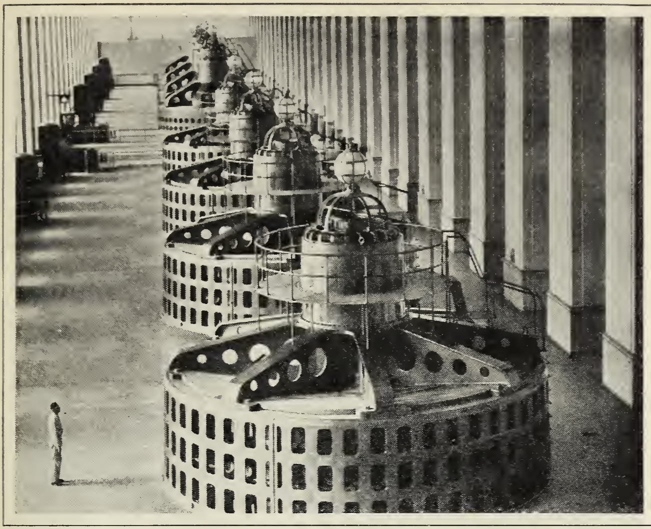
D. How is the Energy of Coal and Falling Water changed into Electrical Energy?

You have now studied through experiments the principles which govern the generation of electric current. The quantity of electrical energy generated by the laboratory instruments you have used was of course so small as to have no practical value. As you look around you and see the universal use of electricity, it is obvious that the same principles you have observed must be applied on a large scale. So they are in the modern power house. Let us study this application.

Have you ever visited a power plant? You recall hearing the hum of many generators like those shown in Fig. 278. What a contrast there is with the tiny generator shown in Fig. 265! Yet they work on the same principle. In generators such as those in Fig. 278 enormous coils of wire are turned through a strong magnetic field. As a result a powerful current of electricity is set up and carried away in the wires leading from the generator. If you could look at this generator in action, you would see that the shaft is turning very smoothly at a speed of about a hundred turns a minute. If you will think about the matter, you will realize that you are seeing on a large scale what you saw on a small scale when you thrust a magnet into a coil of wire or when in your simple generator you turned the coil with your finger between the poles of the pair of field magnets. In either case you can come to the conclusion that as a coil of wire is turned round and round in a magnetic field, electrons move back and forth in the wire. In the power plant, wires lead from the generator to the lights in streets and homes, and the lights glow as electrons flow back and forth through them.

In a power plant the principles of the simple generator are applied on a large scale

While these large generators are common to all power plants, there is one big difference between those found in



Tennessee Valley Authority

FIG. 278. The Principles of the Simple Generator which you have observed are applied even in Generators as Powerful as This

The picture shows the generator floor of a hydroelectric plant

various generating plants. This may be brought out by a question. What type of energy is used to turn the shaft, or, as it is called, the rotor, of the generator? Perhaps on your visit to a modern power plant you found near by a large steam-generating plant which changed the energy of coal into the mechanical energy which turned the rotor. Or perhaps you found that the plant was a hydroelectric one in which the energy of falling water did the work. Both these types of energy are used today for the purpose of generating electric power. The use of hydroelectric-power generation is increasing, however, and may some day be the most frequently used type. Perhaps you can think of some reasons for this. Which source of energy is most likely to disappear?

Coal and falling water are sources of energy that may be used in the generating of electricity

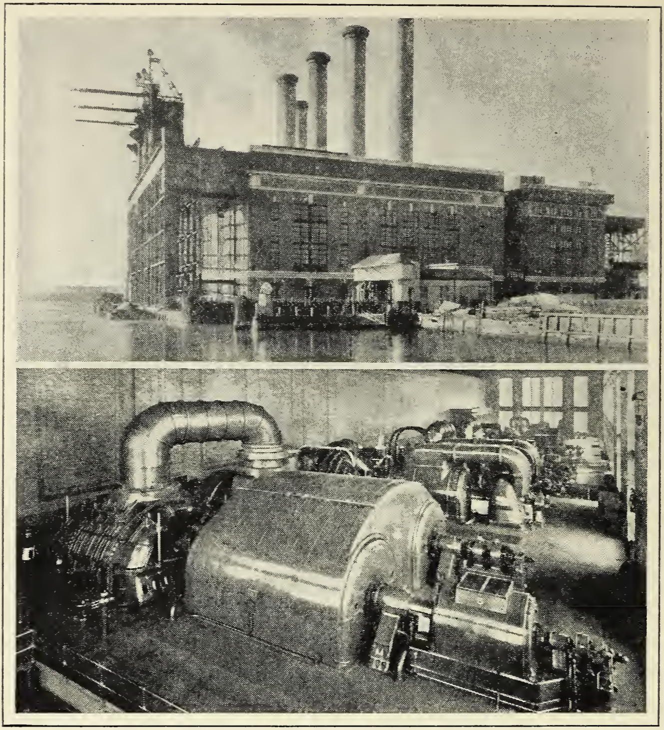
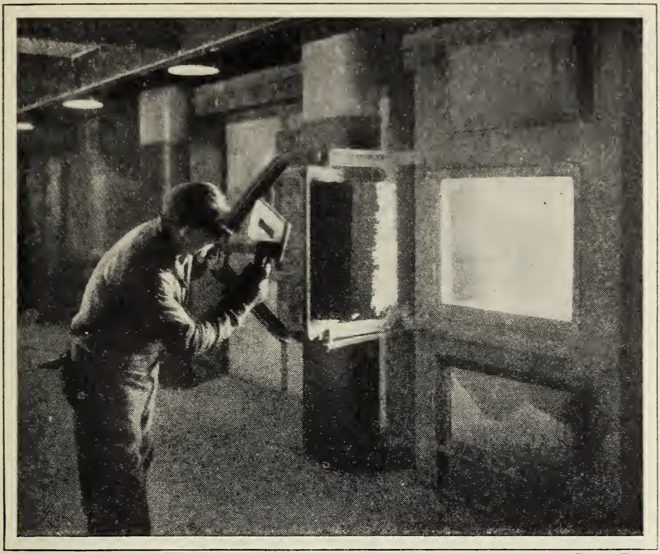


FIG. 279. Large Generating Plants Similar to this one change the Energy of Coal into Electricity

Above, the Hell Gate power station in New York City. Below, part of the generator floor. The steam turbines at the left turn the generators at the right

In Fig. 279 is shown one of the largest generating plants in the United States. It is operated by steam. The possible capacity of this plant is 1,000,000 horsepower. It is located on a river, for barges carrying coal must be able to reach it easily, since the plant at full capacity uses 4000 tons of coal a day. River water is used to the extent of 800,000 gallons a minute. Steam is generated in a number of huge boilers similar to the one in Fig. 280 and is fed at



Power Photo

Fig. 280. Enormous Quantities of Coal are used in the Furnaces of Large Power Houses

Here is one of the furnaces which supply energy to the generators in Fig. 279. The furnaces are mechanically fed

high pressure to immense steam turbines. You have already studied the principles of the turbine, but should see it in its practical application. In the plant we are describing, the rotor of the turbine has twenty sets of blades, and the outer rim at normal speed travels at a rate of 12 miles per minute. This turbine in turn drives the generator shaft. The simple diagram in Fig. 281 may help you to trace the steps by which the potential energy of coal is changed into electrical energy.

Steam turbines use the energy of coal in the generating of electricity

Now let us look at a hydroelectric plant, as shown in Fig. 282. As one approaches the power house, one hears the sound of running water. On the down-river side of the dam, close to the water's edge, is the power house, a

T

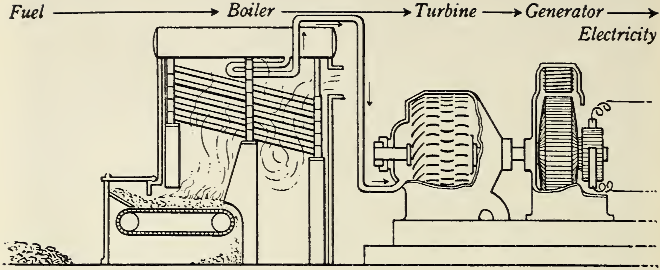


FIG. 281. Can you tell what happens to the Various Forms of Energy used in the Process of Changing Coal into Electricity?

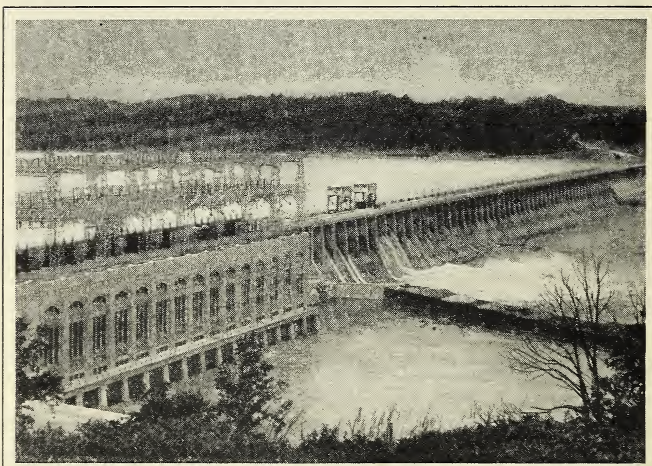


FIG. 282. Water Power is becoming an Important Source of Energy for the Generation of Electricity

This shows the Conowingo Dam and hydroelectric plant in Maryland

low brick building. Water from above the dam is turned into a tunnel and flows from the tunnel through the pipes to the water wheels beneath the power house. Fig. 283 shows this flow in a typical plant. There may be several wheels and an equal number of generators. A pipe leads to each wheel. Suppose we follow the flow of water through one of them. As you can see from the diagram, water falls through a vertical distance (called the head) sometimes as great as 200 feet in getting from the opening above the dam to the turbine on the shaft below the generator.

In a hydroelectric plant water turbines change the energy of falling water into electricity

The falling water turns a large turbine wheel like the one in Fig. 284. With the plant operating at full capacity some 92,400 cubic feet of water flows through the turbine in one minute. How much energy does this represent? It may be measured in horsepower. One cubic foot of water weighs 62.5 pounds, and the water falls through 200 feet. Energy released each minute is equal to 1,155,000,000 foot-pounds ($92,400 \times 62.5 \times 200 = 1,155,000,000$). You may recall from your study of work and power that work at the rate of 33,000 foot-pounds a minute, or 550 foot-pounds a second, is work at the rate of 1 horsepower. In this generating plant we are describing, energy may be obtained for work at the rate of 35,000 horsepower ($1,155,000,000 \div 33,000 = 35,000$).

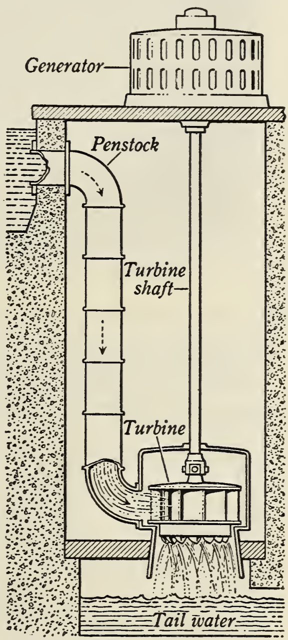
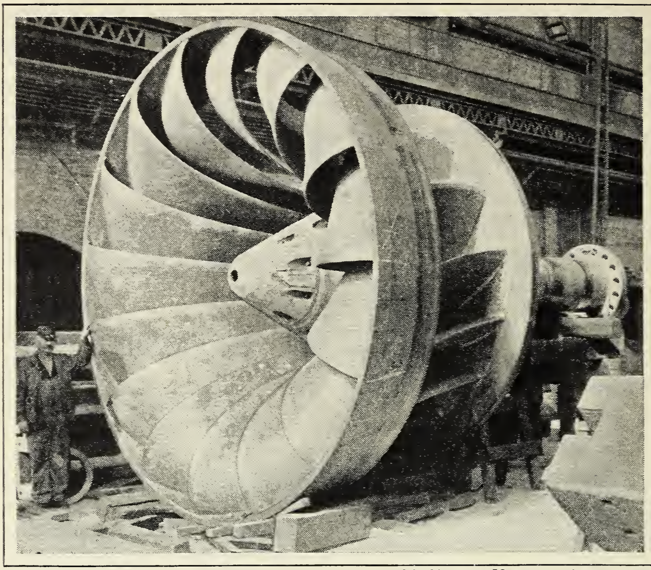


Fig. 283. As the Turbine turns, the Energy of Falling Water is changed to Electricity



Allis-Chalmers Manufacturing Company

Fig. 284. The Energy of Falling Water is used to turn Turbine Wheels as Large as the one shown Above

From these descriptions you can easily see that powerful forces are used to run large generators in a power station. In this large generator the rotating part weighs some 320 tons and is more than 15 feet in diameter. The shaft of the turbine is attached to the rotor of the generator, which turns as the force of the falling water drives through the turbine. If you lived in the neighborhood of this dynamo, you might be able to trace the wires from the light socket in your room back to this generator. This flow is diagramed in Fig. 285.

The generators in a water-power plant are usually turned by the use of turbines

You now understand how energy of coal and falling water is changed into electrical energy. The huge generator in the power plant is similar to the little one used in the demonstration. In the power plant the kinetic energy of

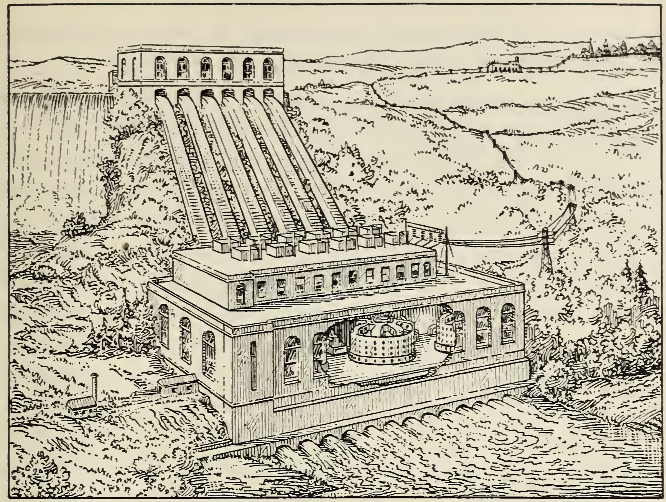


FIG. 285. The Energy for Electric Light in your Room may have its Origin in a Powerful Hydroelectric Station

Do you know how the electricity you use is produced?

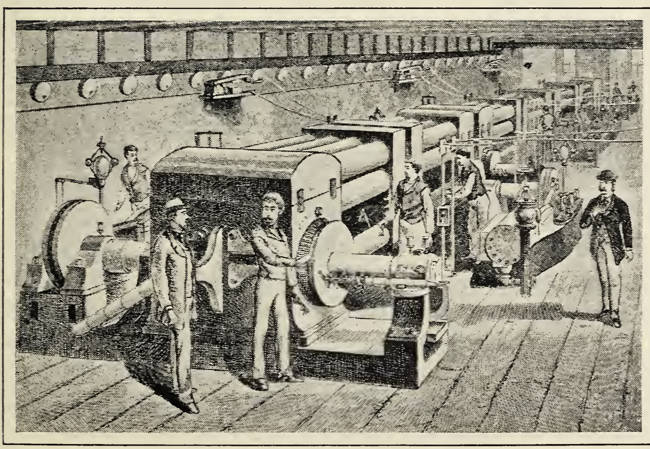


FIG. 286. The First Edison Station, shown here, was a Far Different Place from the Modern Power House

steam or of falling water is changed to electrical energy, and the electricity runs off through the wires.

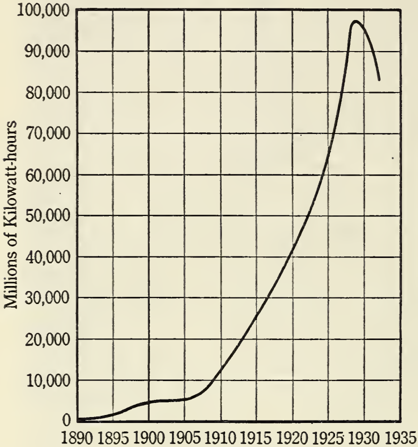


Fig. 287. There has been a Tremendous Increase in the Use of Electrical Energy during the Last Fifty Years

What explains the drop in use since 1929?

As in the case of the development of the railroad the gradual development of electrical energy on a large scale has brought about some tremendous changes in the lives of people. Just two contrasts may help you to realize more clearly how rapid the development has been. Contrast the original Edison station in New York (shown in Fig. 286) with the modern one you saw in Fig. 278. Study the use of electric power as shown in the graph in Fig. 287. What do you think some of the changes have been which have accompanied this growth?

E. How is Electricity Measured?

Electricity, like other forms of energy, is measured in terms of what it will do. Evidence of what a current will do, that is, of the strength of the current, is in the strength of the magnetic field about the wire, the amount of heat it will produce as it flows through a wire, the chemical changes it will produce, and in other observations. All these may be measured. The units used in the measurement of electricity are (1) amperes, (2) ohms, (3) volts. You have heard these terms. What do they mean?

If electricity is a flow of electrons, there must be a rate of flow. This rate is measured as the number or quantity of electrons flowing past a point in a unit of time. An ampere may be thought of as a measure of the quantity of electricity flowing past a point in one second. A current of two amperes will do twice as much work as a current of one ampere.

The ampere is a unit used to measure rate of flow

This quantity of current may also be measured directly in terms of chemical effects it will produce. Let us illustrate. In electroplating it is supposed that a copper atom is formed from a copper ion when it combines with two electrons; thus,

$$Cu^{++} + 2 \text{ electrons} \longrightarrow Cu^{\circ}$$

It is possible to calculate the number of atoms of copper in one gram, and therefore the number of electrons required to plate out one gram of copper. Without explaining this at length it may be said that current flowing at the rate of one ampere and continuing for about fifty minutes will plate out one gram of copper.

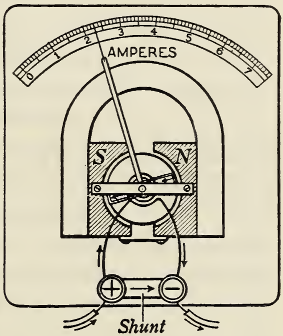


Fig. 288. The Ammeter is an Instrument used to measure Rate of Flow

This one is used to measure direct current. What is the purpose of the shunt?

In common practice, however, the quantity of electric current is measured in another way. A flow of electricity at the rate of one ampere will produce a magnetic field of definite strength. This may be measured by the use of an ammeter. In Fig. 288 you will find a diagram of this instrument as it is used to measure direct current. Notice that only a small fractional part of the electrical energy flows through the coil, most of it going through the shunt. But even the small part flowing through the coil is sufficient to magnetize

The ammeter is an instrument used to measure rate of flow

it and cause the needle to turn. As you can imagine, the strength of the current determines the distance the needle turns. Suppose one ampere is flowing. The pointer swings a certain distance. Suppose two amperes are flowing. The pointer swings twice as far. As you can see from the diagram, marks on the dial indicate how far the pointer should swing for currents ranging from one to seven amperes.

Other types of instruments must be used to measure the strength of alternating current. But in alternating current, as in direct current, the strength is commonly measured by measuring the strength of the magnetic field about the wire in which the current is flowing.

The ohm is the unit used to measure resistance to current flow

As current flows through a wire, there is always some resistance. There is more resistance in a fine wire than in a thicker one of the same material. Similarly there is more resistance to flow through a long wire than through a short one. There are great differences in the resistance of different substances. A copper wire offers relatively little resistance, a nichrome wire such as is used in an electric toaster offers great resistance. The unit for measuring resistance is called an ohm.

The volt is a unit used to measure force of flow

It should be possible for you to recognize that some force is required to drive electrons against a resistance. The driving force of the electron is measured in terms of the volt. The ampere, you will recall, is a measure of rate of electron flow. The ohm is a measure of resistance to electron flow. One volt is a force sufficient to cause one ampere of current to flow against a resistance of one ohm.

From your study of work, power, and energy you know that work is done as a force moves through a distance, and you know that power is a measure of the rate at which work is done. For example, water power is the quantity of water multiplied by the distance through which it falls.

Electric power is really measured in a similar manner. It is quantity of electricity per second (amperes) × electric pressure (volts). The result of this multiplication gives us the unit of electric power commonly used, called the watt. In full, then, we have

The watt is the most common unit of electric measurement and is the rate times the force of flow

$$\text{Amperes} \times \text{volts} = \text{watts}$$

By substituting figures in this expression you will see that one ampere of current flowing with a pressure of one volt does work at the rate of one watt.

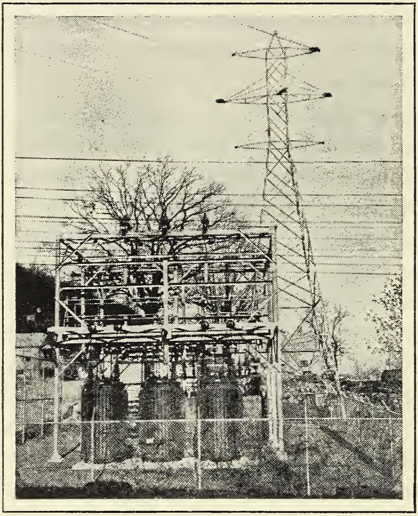
Obviously the watt is a small unit. For convenience a unit of 1000 watts, called the kilowatt (kw.), is commonly used. One kilowatt is equal to about three fourths (0.746) of a horsepower. Perhaps you may gain a better idea of the amount of energy involved in 1 watt by studying again the large generator you saw in the power house. In this the energy of falling water flowed at the rate of 35,000 horsepower. If there were no losses, this would produce 46,667 kilowatts ($35,000 \div \frac{3}{4} = 46,667$). Electricity leaves this generator with a pressure of 12,000 volts. Since it is an alternating-current generator, electrons are not flowing in one direction but moving back and forth. By using the expressions you have just learned you can see that current is flowing back and forth at the rate of 3888 amperes (46,667,000 (watts) ÷ 12,000 (volts) = 3888).

The kilowatt equals 1000 watts

Now let us apply these principles in common use. When you pay for electrical power, you really pay for energy to do work at a certain rate for a certain period of time. The power company charges you for the number of kilowatt-hours of energy you use. Thus if you use 3 kilowatts of energy for 4 hours, you will be charged for 12 kilowatt-hours of energy. Let us see how this might be used in an ordinary household. An electric flatiron or an electric toaster uses about $\frac{1}{2}$ kilowatt. In 2 hours, therefore,

The charge for electricity is based on the number of kilowatt-hours of energy used

it will use 1 kilowatt-hour. The lamps used in the home vary from 25-watt lamps, which are not very bright, to possibly 250-watt lamps. Suppose that during the day an electric iron was used in your home for an hour, the toaster was used at each of three meals (totaling an hour), and during the evening five 40-watt lamps were burning for 3 hours. If the rate for electricity in your town is 5 cents a kilowatt-hour, how much would your electricity bill be for the day? Let us count it up: 500 watt-hours for the iron, 500 watt-hours for the toaster, and 600 watt-hours ($5 \times 40 \times 3 = 600$) for the lamps. This makes a total of 1600 watt-hours, or 1.6 kilowatt-hours. At 5 cents a kilowatt-hour your bill would be 8 cents in all. Perhaps you would like to make a study of the amount of electric power you use in your own household.



Ewing Galloway

Fig. 289. Transformers Similar to these are used to step up the Voltage of the Current generated at the Power House

If you should make such a study, you would find that heating devices require the most current of any of the devices used in the home. A toaster or an iron uses about twelve times as much current as a 40-watt lamp. The motor of the vacuum sweeper uses less current than a 40-watt lamp uses. The motor of an ordinary washing machine such as is used in homes uses less than one half as much current as an ordinary iron.

F. How is Current distributed from the Generator to Homes and Factories?

Now that you have seen how electricity is generated and how it is measured, let us consider just how this energy gets into your home. One might answer this question rather easily by saying that it flows along wires. The answer would be correct, but it would not be complete; for many things happen to the electric current from the time it leaves the power house until the time it is used by you.

Imagine that you are back in the power station again and that you have asked this question of one of the engineers. He would probably ask you to come outside, where he would show you a number of transformers similar to those in Fig. 289. If you looked closely, you would see a sign on the fence near by reading

DANGER—154,000 Volts

This would seem strange, for you will remember that the current left the generators at 12,000 volts. Evidently something has happened to it. If you asked the engineer about it, he would tell you that the current has been transformed, or "stepped up." But, he would hasten to add, the amount of power (kilowatts) remains the same. Remember the expression, Amperes × volts = watts. If the watts remain the same and the voltage becomes higher, the amperage must of course be lower. Do you see why? The process of changing the current has been one of lowering the amperage and raising the voltage.

Current leaving the power plant is usually stepped up by raising the voltage and lowering the amperage

Why is the current stepped up in this way? And how is it done?

The answer to the first question must be brief. You may learn more about it from advanced books on electricity. It may be shown that heat losses are less at high voltage

and low amperage than at low voltage and high amperage. Thus you may decide that current is sent out from the power station at high voltage simply for the sake of economy. This is not important when sending small amounts of current, but when sending large amounts, as over high-tension wires, it is very important.

The stepping up of current is done for purposes of economy

But let us consider how this change is accomplished. As you have learned, the instrument in which the current is stepped up is called a transformer. Some experiments will help you to understand how a transformer works.

Arrange two coils of wire, some dry cells, and a galvanometer as in the upper diagram in Fig. 290. From this diagram you will see that in one circuit there are a coil, a switch, and the dry cells. In the second circuit are another coil and the galvanometer. Notice that the two coils are not connected with one another in any way. Now close the switch. Were you surprised to see that the galvanometer needle moved? It swung to one side, but immediately moved back again to the center. Now open the switch. Again the needle moves, this time in the opposite direction, and then swings back to center. Try it again. The same thing happens. What does this mean? Evidently at the moment when the current begins to flow in one coil a current is started in the other coil. Also, when the current in the first coil stops flowing, a current flowing in the opposite direction is started in the second coil. It cannot be the flow of the current in the first coil which produces the current in the second coil, for there is no deflection of the galvanometer needle while the switch is closed. What explanation is there?

A transformer is a mechanism for changing the voltage

In order to explain this you must recall two things about electricity and magnetism: First, a current of electricity generates a magnetic field about a wire. Second, when a magnetic field moves with relation to a conductor, a cur-

rent is produced in the conductor. It follows, then, that when the magnetic field moves or when the conductor moves, a current is produced. Now what happens when you make and break the current in your apparatus? At the instant the switch is closed the space about the wire in the first coil becomes a magnetic field. Lines of force start from the wire and spread out into space. As they spread through the second coil, they produce the same effect as that from moving a magnetic field through the coil. Do you see why? An induced current, then, flows in the wire. When the switch is opened, the magnetic field collapses. The effect is the same as before. An induced current flows in the wire, but this time it is in the opposite direction.

The principle of a transformer is explained by the properties of magnetism

Now wind two coils on an iron ring, as shown in the lower diagram in Fig. 290, and close and open the switch again. This time the galvanometer needle swings farther, indicating a stronger current. You have already learned that lines of force tend to pass from air into iron. Thus the lines of force set up around the coil when the current starts tend to collect in the iron core and are kept more closely together in the vicinity of the coils instead of spreading out through space. Thus more of them cut the second coil, and a stronger current is produced.

As the alternating current moves back and forth in one coil, it causes the magnetic field around it to vary. Remember that as the direction of current through an electromagnet changes, the poles reverse. This produces an alternating movement of electrons in the second coil.

At this point you might wish to repeat your experiments with your demonstration transformer for the purpose of checking upon the principles we have just presented.

It is the application of these principles which makes the transformer possible. Experiments have shown that the voltage in the coils is proportional to the number of turns of wire. The coil directly attached to the source of current

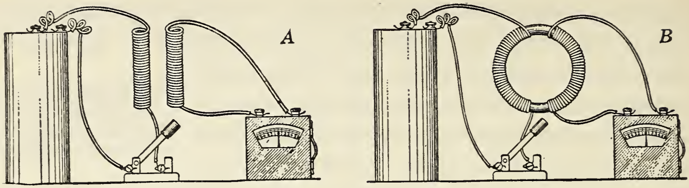


FIG. 290. Arrangement of a Transformer

A, an induced electrical current may be made to flow in a coil of wire not connected to the source of the electrical current. *B*, the induced current becomes stronger when the coils are wound on an iron ring

is called the primary. The coil in which a current is induced is called the secondary. If the secondary has twice as many turns as the primary, the voltage will be twice as high as the voltage in the primary. This would be called a step-up transformer. Now you can see what happens to the current which leaves the power plant at 12,000 volts. It passes through a complex transformer of the step-up type and is raised to 154,000 volts. But obviously it is changed again, for the current you use at home is only 110 volts. How is this done? Refer again to your simple transformer.

When the current was stepped up, the secondary coil had many more turns than the primary. Suppose the conditions were reversed, and the secondary coil had only half as many turns as the primary? Obviously the voltage of the current from the secondary coil would be only half as high as that from the

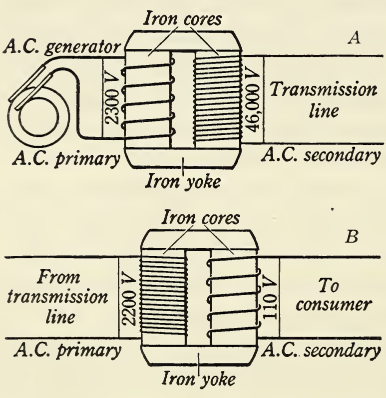


FIG. 291. By Changing the Number of Turns of Wire in the Primary and Secondary Coils a Transformer may be made to step up or step down the Current

Why should *A* be a step-up transformer and *B* a step-down transformer?

primary. Such an arrangement is called a step-down transformer. Current is stepped up to high voltage and is stepped down to low voltage.

An additional factor needs to be considered. While current is transformed, the *amount* of power does not change. In other words, just the same amount of power (watts) flows in both coils, except for a small loss, mostly as heat. But recall what you learned about the relationships between volt-

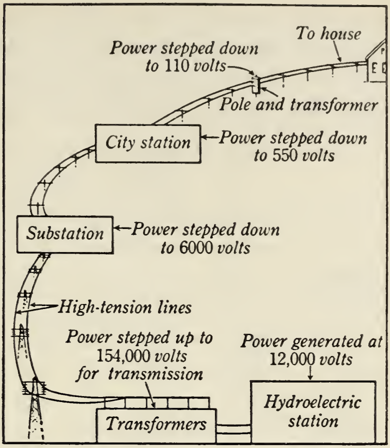
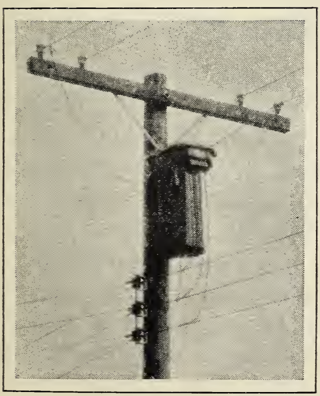


FIG. 292. The Electric Current generated at the Power Station is changed Several Times in Voltage and Amperage before it reaches your Home

Do you know why each of these changes is made?

age and amperage. You have already seen that after the current has passed through the step-up transformer, the voltage has increased. You also found that the amperage decreased. If you will study this a little, you will see that obviously the coil which carries the low voltage carries a greater current in amperes. Since amperage measures *rate* of flow, a wire carrying a high amperage must be larger than one carrying a low amperage. In a



Westinghouse

FIG. 293. This Common Form of Transformer steps down the Current to 110 Volts

step-down transformer, therefore, the primary is composed of many turns of fine wire and the secondary of a few turns of heavy wire. The step-up transformer is just the opposite. Do you see why this is? Perhaps some diagrams will help. Fig. 291 is a diagram of a simple transformer. In *A* it is connected up as a step-up transformer. In *B* it is shown being used as a step-down transformer.

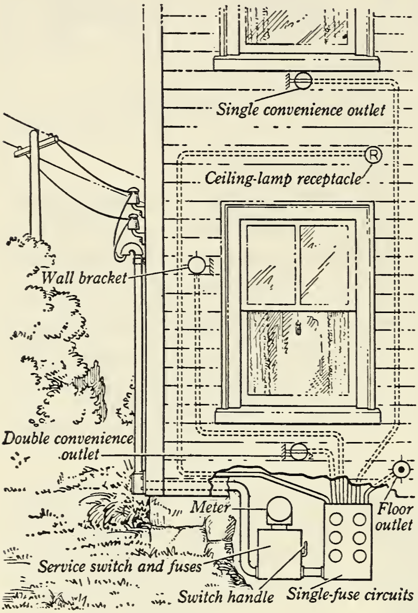


Fig. 294. Electric Current enters the House through a Switch, Meter, and Fuse Box

Notice how the wires lead to the various outlets and how each circuit is protected by fuses

Current may, of course, be taken from a high-tension wire at relatively low amperage, for only a small portion of the total current may be taken off at one station.

Shall we now pick up our current again on the power line after it has been stepped up to 154,000 volts? After following it some 200 miles we find that it branches off to other transformers. The large transformer is a substation. Here current may be stepped down to 6000 volts and be sent out over smaller wires to a near-by city. Upon reaching the city distributing station we follow the current through more transformers in smaller substations in which it is reduced to 550 volts and sent out to different parts of the city. The succession of transformations by which current is generated at 12,000

volts, stepped up to 154,000 volts, and then stepped down is shown in Fig. 292. A line that carries current to residences leads through still another transformer, like the one shown in Fig. 293, in which the current is stepped down to 110 volts. From this last transformer the wires lead to separate residences.

Carrying current at 110 volts, the wires enter the house through a switch, meter, and fuse box arranged as shown in Fig. 294. Each of these mechanisms serves a special purpose. When the switch is open, current is cut off from the house. The amount of electrical energy used in the house is measured in kilowatt-hours through the meter. One is shown in Fig. 295. Can you read it? The fuses serve as a protection, preventing too much current from flowing in the house wire. Fig. 296 shows a cross section through a fuse. If too much current flows, on account of overloading or on account of accident, a fuse blows and cuts off the current flowing through the house.

Different uses of electricity require different voltages

Sometimes the voltage of the house current is reduced so that it may be used for other purposes, such as to ring the doorbell. In this case a small transformer reduces the 110-volt house current to about 6 volts. Small transformers are also used in your radio set. Perhaps you can think of other uses.

Do you now see why alternating current is used so often? In the first place, an alternating-current generator is more economical to

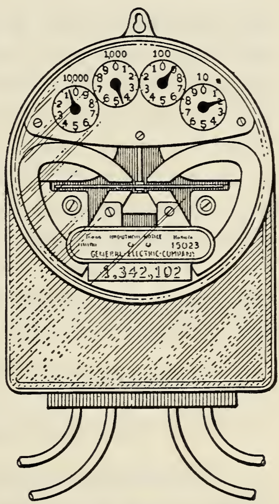
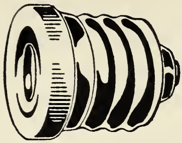


Fig. 295. A Kilowatt-Hour Meter measures the Amount of Electricity you Use

Do you ever check your electric-light bill against the meter?



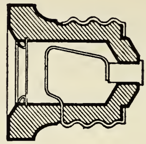


Fig. 296. When Too Much Current flows through a Wire, the Fuse "Blows"

Does the cross section of the fuse explain why it "blows"?

operate. But of even more importance is the fact that the voltage of alternating current may be stepped up or down by means of transformers. The transformer is of no use with a direct current. You can see some of the difficulties which would arise if all current had to be of the direct type.

The generator is the mechanism used for the generating of electricity. Forces are applied to turn a coil of wire within a magnetic field. The forces used may come from either of two sources: the energy of steam or the energy of falling water. These forces are usually applied to the rapidly moving shaft of the generator by means of turbines. Two types of current may be produced: A.C. and D.C. The former is most frequently used, since its voltage may be stepped up or stepped down. This is done by means of a transformer, another instrument using the principles of magnetism. Electrical energy may be measured in terms of kilowatt-hours.

Can You Answer these Questions?

1. What is meant by the statement that the principle of magnetism is used in the generating of electricity?

2. What principle or principles may be used to explain the current of electricity which is set up when an armature is turned between a pair of magnets?

3. What is the difference between a generator and a motor?

4. What is the difference between A.C. and D.C. current?

5. What are some of the essential differences in design between a coal-operated power station and a hydroelectric one?

6. What are the units of electrical energy called the ampere, ohm, volt, watt, and kilowatt? How are they used to measure electric current?

7. Why is the current generated at the power house usually stepped up before it is sent over the wires? How is this done?

8. What is the principle of a simple step-up transformer? of a simple step-down transformer? How is it possible to control the extent to which the voltage is transformed?

9. What is the principle of a fuse?

10. What is meant by a magnetic field?

11. Why should the different position of the brushes in a generator produce different types of current?

12. Can you show by mathematics that changing the amperage of an electric current with the number of watts constant makes a change in the voltage? that changing the voltage with the number of watts constant makes a change in the amperage? that changing the number of watts with the amperage constant makes a change in the voltage?

Questions for Discussion

1. Does the speed at which the armature of a generator is turned between the magnets have any relationship to the amount of current produced?

2. What factors of the environment do you think might make a coal-operated electric station more economical than a hydroelectric one and vice versa?

3. What are some of the difficulties which would arise if all current were of the D.C. type? What are some of the practical advantages of the A.C. type?

4. Some types of electrical machines are marked for A.C. current only. Others are marked for D.C. current only. Still others are marked for A.C. or D.C. current. Why should not all work with either type of current?

5. How do you think it is possible to construct a generator so as to produce current of exactly the proper voltage?

6. Do you think that some day all electricity may be produced by hydroelectric power? Why?

7. It has been said that the use of electricity has revolutionized methods of manufacturing. Can you support or attack this statement by any specific examples?

Here are Some Things You May Want to Do

1. Make a study of the costs of electricity in your community and neighboring communities. What differences do you find? What explanations are there for these differences?

2. Take a trip to a near-by power station and discuss the application of simple electrical principles you see there.

3. Look up information from which to write short biographies about such scientists as Volta, Galvani, Ohm, Ampere, and Watt.

4. Find information about some large hydroelectric plants such as those at Muscle Shoals, Boulder Dam, Conowingo, Niagara Falls, or Keokuk, Iowa. Consider such questions as possible output, cost, area served, and whether the station is privately or publicly owned.

Chapter XXIII · How is Electrical Energy used in the Telephone and Radio?

Come back with us in time to June 2, 1875. In a small house in Boston two men are at work upon an electrical circuit which one of them, Alexander Graham Bell, believes can be used to carry the effects of sound waves. So far their work has been unsuccessful. But suddenly the second man, Thomas A. Watson, who has been working alone in the attic, is disturbed by Bell, who rushes up, shouting, "What did you do then? Don't change anything. Let me see!" Watson explains that he has been tinkering with the transmitter, and Bell tells him that he has heard that sound at the receiving end of the line. Then a line was run between two other rooms, and further experiments were made. Finally on March 10, 1876, for the first time Watson heard Bell call him over a telephone, saying, "Mr. Watson, please come here; I want you."

From that time progress was rapid, though not easy. Difficulties about money delayed Bell and his helper. They even resorted to lecture tours. Fig. 297 shows Dr. Bell with an early model of the telephone. Finally the difficulties were overcome, and commercial development began.

By 1880 there were over thirty thousand telephones in the United States; by 1900 there were over six hundred thousand; and by 1910, close to six million. Today, of course, the telephone is an extremely important feature in our civilization.

Now look at another picture. It is December 12, 1901. In a small room inside the signal station at St. John's, Newfoundland, sits a young Italian, Guglielmo Marconi, with a crude set of headphones clamped over his ears. Outside, a storm is raging. After much effort a kite has been

Fig. 297. The Telephone was not always the Neat, Compact Instrument it is Now

This scene shows Mr. Bell sending the first long-distance telephone message

raised, carrying an aërial wire attached to a receiving set. Marconi listens eagerly. Suddenly he presses the headphones to his ears. From Cornwall, England, comes the sound of three dots representing the Morse code for the letter *s*. For the first time a wireless message has crossed the Atlantic, and a new means of communication has been established between the Old World and the New.

Remember the year, 1901. Think of the progress that has been made in the short time between that year and

today, when with a mere twist of a dial you can hear music and speeches from all parts of the world. Your fathers can remember when there were no radios, and your grandfathers can probably remember when there were no telephones. Yet 40 per cent of American homes had radios in 1930, and about an equal number had telephones.

The telephone and the radio are comparatively recent inventions

Perhaps the telephone and the radio seem strange instruments in many ways. How is it possible that a message spoken into a telephone transmitter may be sent along a wire and be delivered almost instantly at a destination perhaps thousands of miles away? How is it possible that a message may pass through space with no obvious carrier, such as a wire, and be delivered through a radio receiving set that is connected in no material way to a microphone?

Perhaps some of your previous work in science may help in the search for answers to these questions. Let us recall some of it for you. You have seen that the energy of electricity may be sent along a wire. Has this any relationship to the telephone? You have seen, too, that energy may be sent through space as radiant energy. Does this explain some of the things you have noted about the radio?

A. What is Sound?

Let us study common means of producing sound. Hold your throat lightly with the fingers of one hand. Now read a few lines of this book out loud. Do you notice a vibration in your throat? What causes it? You know something of the tube called the windpipe, leading from your throat to your lungs. In your throat, at the upper end of this tube, is a small boxlike structure called a larynx. The location of it is shown in Fig. 298, *A*. Across the larynx, as pictured in Fig. 298, *B*, are the vocal cords. During ordinary breathing these cords are relaxed. When you speak, how-

The sound of the voice is produced by the vibration of the vocal cords in the larynx

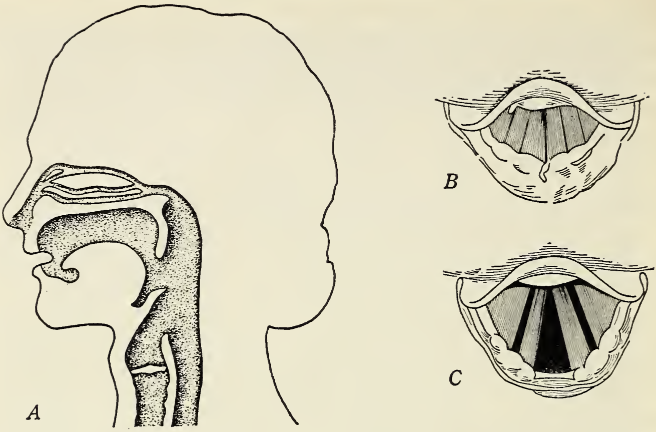


Fig. 298. The Sound of the Voice is produced by the Vibration of the Vocal Cords in the Larynx

A, a cross section of the throat, showing location of the larynx; *B*, the vocal cords vibrating while singing; *C*, the vocal cords at rest

ever, you tighten the cords and force air between them. This causes them to vibrate, as shown in Fig. 298, *B*. It is this vibration that produces the sound of your voice.

Fig. 299. You can make a Model Diaphragm by Stretching Two Pieces of Rubber over a Glass Tube

You can demonstrate this in another way if you wish. Make an artificial larynx by stretching two pieces of rubber from a toy balloon over the end of a narrow glass tube (Fig. 299). The two pieces of rubber should overlap just a little at the center of the tube. Now blow vigorously into the other end of the tube. The vibrating rubber produces a squawking sound in much the same manner as vibrating vocal cords produce the sound of your voice.

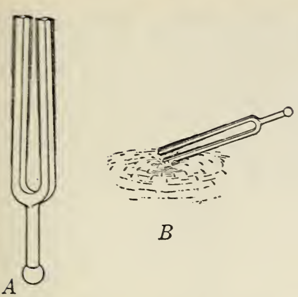


Fig. 300. Do you believe that a Tuning Fork does Vibrate?

Set a tuning fork in vibration, *A*, and touch it to the surface of some water, *B*

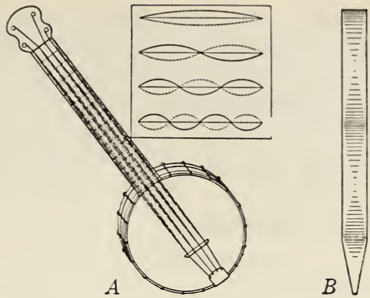


Fig. 301. Sounds are produced by Vibration

A, vibration of banjo strings; *B*, vibration of a column of air in a pipe organ

You may experiment with other vibrating objects. Strike a large tuning fork gently with a wooden hammer. If you observe closely, you may see the prongs, or points, vibrating. Touch the sounding fork to the surface of some water, as shown in Fig. 300, *B*. The water splashes. Obviously the fork is vibrating. Other examples of such vibrations and the fact that they produce sound are common to everyone. You may draw a bow across violin strings or pluck the strings of a banjo or guitar. These strings vibrate as shown in Fig. 301, *A*. The result is sound. You press a key on the board of a pipe organ. Air, entering one of the pipes as shown in Fig. 301, *B*, sets the air column to vibrating, thus causing a sound. When you hit a drum, the drum top vibrates. From these and other experiences you come to the conclusion that sound is caused by vibration.

Sound may be produced by the vibration of many different kinds of objects

How is it that sound travels from a vibrating body to your ear? If you could examine the vibrating tuning fork carefully, you would find that both prongs are vibrating at a uniform rate. A fork with the tone of middle C on the piano, for example, vibrates at the rate of 256 vibrations per second. A fork with a higher pitch vibrates more

rapidly, and one with a lower pitch more slowly. Look at the prongs of the vibrating fork shown in Fig. 302. Each prong moves first in the direction of *a* and then in the direction of *b*. The number of vibrations, since its tone is middle C, is 256 in each second. What happens during the vibration? As a prong moves toward *a*, it presses in that direction the molecules of surrounding air. As it moves toward *b*, the pressure in the direction of *a* is reduced. The molecules rush back from *a*, following the prong toward *b*. Again the prong moves toward *a*. Again the molecules are forced in that direction. Imagine this process repeated many times per second, and you will see that with each vibration there is produced alternately on each side of the prong a condensation and a rarefaction. In other words, on each side of the prong the molecules are alternately pushed closer together and spread farther apart. You will see, too, by a study of Fig. 302, that a condensation is produced on one side as a rarefaction is produced on the other.

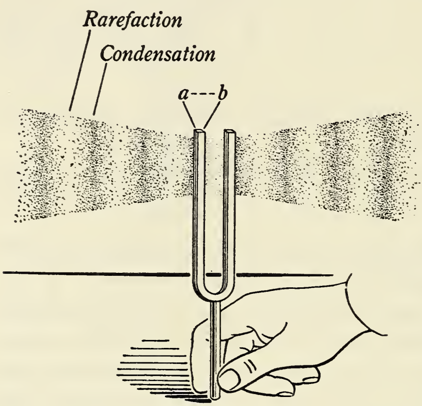


Fig. 302. Sound is carried by the Condensation and Rarefaction in the Air

Sound is carried by condensation and rarefaction in the air

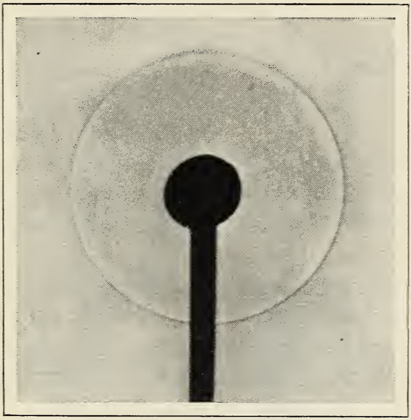
Let us state the observations in another way. The molecules pushed by the prong strike against other molecules, and the condensation moves outward. This is followed immediately by a rarefaction during which the molecules move in the opposite direction. If you could watch a

molecule as a sound wave passes, you would see it move back and forth with each succeeding push. Study Fig. 302 again.

Regular motion passed along from one group of particles to another is called a wave motion. Remember that the condensation represents molecules pushed closer together, and the rarefaction represents molecules spread farther apart. The length of the sound wave is from the center of one condensation to the center of the next. In sounds of higher pitch the sound waves are shorter, and in sounds of lower pitch the waves are longer.

The pitch of the sound depends upon the length of the sound waves

This disturbance which we have called a sound wave will travel through air in much the same way that a water wave travels on the surface of a smooth lake. Fig. 303 is a photograph showing the effect of a sound wave. The sound wave travels outward in every direction. The water wave, however, travels only over the plane surface.



Professor A. L. Foley

Fig. 303. A Sound Wave travels in much the Same Way as a Water Wave

The photograph was taken $\frac{1}{10,000}$ second after the sound wave started from the center

It is easy to demonstrate that air acts as a carrier of sound. Arrange an electric bell in a bell jar connected with an air pump (Fig. 304). Close the switch, and the bell rings clearly. Now start the air pump and remove the air from the jar. The sound of the bell will become fainter and fainter until you cannot hear it at all. Yet the clapper continues to hit the

Air is a carrier of sound waves

bell. Now allow air to enter the jar again. The sound of the bell gradually gets louder.

Sound has three properties: pitch, loudness, and quality

So far we have discussed one property of sound: its tone, or pitch. This, as you have seen, depends upon the number of times the vibrating body vibrates per second. But sound has other properties. If you strike a fork lightly, it produces a soft tone; if you strike it harder, it produces a louder tone. The reason is that the harder blow causes the prong to vibrate through a wider range. Thus it disturbs the molecules about it more violently. The distance through which the molecules move on account of vibration is the amplitude, or size, of the wave. This increased violence of vibration, or amplitude, is interpreted by the ear as a louder sound. Remember, however, that the vibrations of the fork are at the same rate, no matter how hard you strike it. Loudness is not related to pitch.

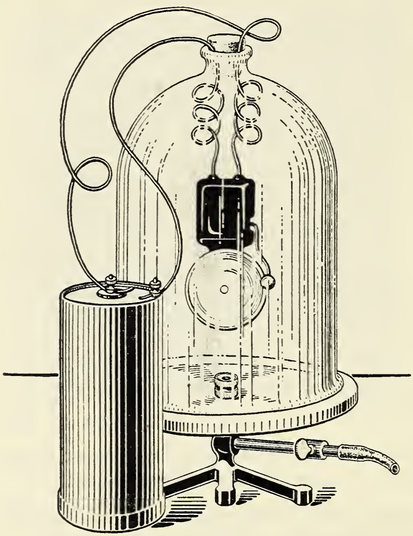


Fig. 304. There can be No Sound Waves in a Vacuum

Another property of sound is called quality. Tones from a violin and from a banjo may have the same pitch. Yet they may be distinguished. Imagine a great opera star singing high C. Now imagine some amateur singing it. The property of sound that makes it possible to distinguish one tone from another of the same

pitch is called quality. The important thing to remember is that the three properties of sound — pitch, loudness, and quality — are carried by the sound waves.

How fast does sound travel? It obviously takes some time for condensations and rarefactions to move along through the air. A common observation may help to make this clear. You have doubtless seen a lightning flash and waited for the thunder. The flash starts the sound waves coursing through the air. Perhaps you have counted the seconds between the flash and the time the sound reached your ears. You know that sound evidently travels more slowly than light. Very careful measurements have shown that sound travels through air at the rate of about 1100 feet each second. If you counted an interval of five seconds between the flash of lightning and the sound of thunder, the flash was about 5500 feet, or a little more than a mile, away. You know, too, that you may see the steam from a distant whistle a few seconds before the sound reaches you.

Sound waves travel in air at a speed of about 1100 feet each second

One of the most obvious things about sound, of course, is that we hear it. If you can see in imagination the effect produced on the molecules of the air by a vibrating body, you may understand how sounds are communicated to your ear. Stretched across the opening leading into the ear is a delicate membrane known as the eardrum. Its position is shown in Fig. 340 (p. 565). It is easy to see how the condensations and rarefactions of sound waves cause the drum to vibrate. The motion of the vibrating eardrum is carried through a chain of small bones to the inner ear. This is a cavity filled with liquid. In it are many nerve fibers. The effect of the different vibrations on these nerve endings is interpreted by the brain as sound. Notice, too, that these effects are interpreted by the ear in terms of the three properties of sound, namely, pitch, loudness, and quality.

The ear is an organ for changing sound waves into hearing

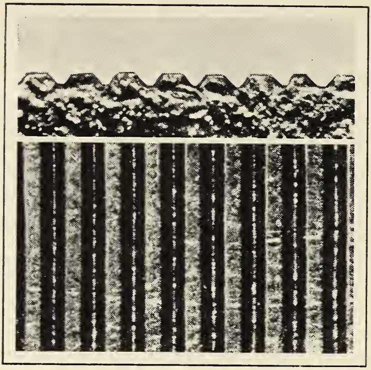


Fig. 305. As the Diaphragm of the Recording Mechanism vibrates, the Needle cuts a Groove in the Soft Wax Record

Above is a cross section of a record. Beneath is a surface view. Both magnified

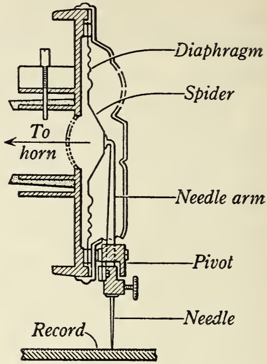


Fig. 306. The Phonograph is an Instrument for Reproducing Sound that has been recorded on a Disk

What part is played by the needle and by the diaphragm?

The fact that sound is a result of vibration has been used in many practical applications. One of the most common is the phonograph, with which you are probably familiar. To understand the way in which the properties of sound are applied in the phonograph, you must consider it from two angles. First, how is sound recorded? In its simplest form the recording mechanism is made up of a horn or other instrument which gathers the sound. To this is attached a diaphragm, so constructed that it can vibrate. A needle is attached to the diaphragm, and in turn rests on a soft wax disk, or plate. Now imagine that someone is singing or talking. The vibrations of the voice pass through the horn to the diaphragm. It vibrates and carries the properties of the voice to the needle. The needle itself moves up and down or from side to side, recording the properties of the voice in the soft wax. Notice the track in Fig. 305.

Second, how is the sound reproduced? Look at the playing mechanism in Fig. 306. A record is placed upon the turn-

table. This record, as you can guess, has been made from a master record, which in turn was made from the original soft-wax disk. Thus it contains exactly the same grooves, or track, as the original. When the record is ready to play, a needle is lowered until it rests lightly in the grooves. This needle is connected to another diaphragm so constructed that it can vibrate. When the phonograph starts, the needle follows the grooves in the record. The movement of the needle is carried as a succession of vibrations in the diaphragm, and these vibrations in turn are changed into the sound which you hear as it comes from the sound chamber of the phonograph.

The phonograph is an instrument for reproducing sound waves that have been recorded on a disk

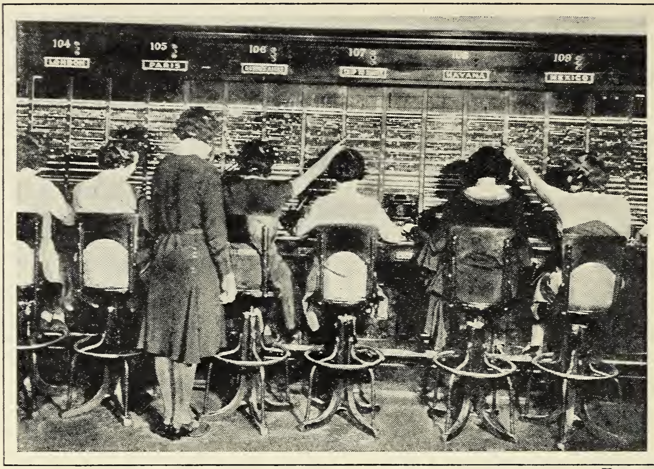
B. How may Sound Waves affect the Flow of Electrical Energy through a Wire?

If you have ever visited a telephone exchange, such as the one in Fig. 307, and have seen the many connections similar to the ones in Fig. 308, perhaps you have wondered just how a telephone really does work. If we tried to explain at length just how this modern telephone exchange works, it would be far too long a story to tell here. But the principles involved in the telephone itself are not so complex. In fact, they are but further applications of some principles you have already learned.

In Fig. 309 notice that there are two circuits, one marked the "primary" and one the "secondary." These circuits are not new to you. From your study of induced currents, you can understand that when a current passes from the battery and through the primary circuit, a current is induced in the secondary circuit. Notice that the transmitter is in the primary circuit. This is important in the explanation which is to follow.

A telephone uses induced currents

Let us look a little more closely at the transmitter which is shown in Fig. 310. If you have ever taken the mouth-



Keystone

Fig. 307. A Modern Telephone Exchange connects All the Main Cities of the World

Do you know the steps of the telephone-radio hook-up which make it possible for a person to talk from the United States to Europe and South America?

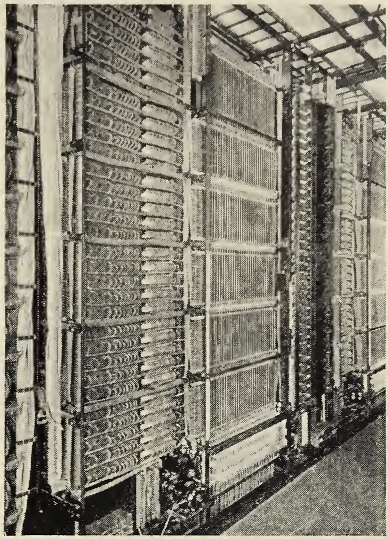
piece off a transmitter, you may have noticed a metal disk directly behind it. This is the diaphragm. A sound made before the mouthpiece of a telephone causes molecules of air to push against the diaphragm. As a result the sound waves move the disk back and forth or, in other words, cause the disk to vibrate.

The diaphragm of a telephone transmitter vibrates as the result of sound waves

If you have looked closely at the diaphragm, you have seen a metal stud, or nail, through the center of it. This stud fastens the diaphragm to one side of a small box. Do you see this in Fig. 310? The box itself is filled with grains of carbon. The front and the back of this box are made of metal, but the metal parts are separated from each other by a ring of insulating material, also shown in Fig. 310.

Now follow the connections of the primary circuit. Notice that one wire is connected to the front of the box

and another to the back. These wires lead to a source of electricity in the central telephone exchange. Obviously in this hook-up a current of electricity in the primary circuit must pass through the carbon in the carbon box. Do you see why? What is the importance of this? Let us imagine that a tuning fork is held before the transmitter and is struck. Condensations and rarefactions similar to those illustrated in Fig. 302 pass into the mouthpiece and strike the diaphragm, causing it to vibrate. The condensations, of course, push the disk inward, and the rarefactions cause the disk to bulge outward. What happens to the carbon particles? Study Fig. 311. As you can see, vibration alternately compresses and releases them. Look at this more closely. When the diaphragm is pushed inward by a sound wave, the front and the back of the box are squeezed together. The particles of carbon inside are then pressed closely together, too, so that they look like Fig. 311, *a*. Does this affect the current of electricity in any way? You will see that when the particles are closer together, there are more paths over



Keystone

Fig. 308. Telephone Communication applies on a Large and Complex Scale Simple Principles of Electricity and Magnetism

How should you like to try to find a short circuit in this automatic telephone switchboard?

The vibration of the diaphragm affects the strength of the current of electricity flowing through the circuit

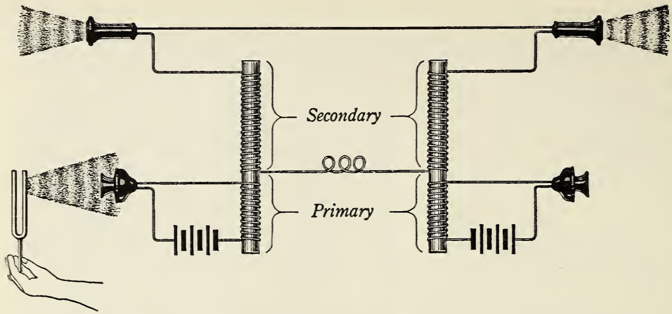


Fig. 309. A Telephone Circuit uses Induced Currents

Can you trace the message from transmitter to receiver?

which the flowing electrons may pass from one side of the box to the other. To state this in another way, at such a time the resistance to the electrical current is lowered, and a stronger current flows through the circuit.

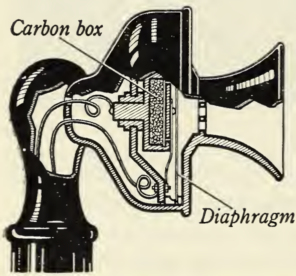


Fig. 310. The Diaphragm of a Telephone Transmitter vibrates as the Result of Sound Waves

The effect of these sound waves is carried over an electric circuit to the receiving instrument

Imagine that the opposite of this is happening, as shown in Fig. 311, *b*. The rarefaction in the sound wave has caused the disk to bulge, and the carbon particles are spread farther apart. The electrons have fewer paths over which to travel, resistance is increased, and a weaker current passes through the circuit.

Thus you see that the condensations and rarefactions in the sound waves set up by the vibrating fork cause differences in the strength of the electric current flowing through the primary circuit. You will recall that induced currents are set up in a secondary as the strength of the current changes in the primary. In the tele-

phone a current similar to the one flowing in the primary is induced in the secondary. The condensations and rarefactions of sound waves are registered in the strength of the current which flows through the telephone circuit. For purposes of illustration we have used a tuning fork. Similar results would be secured with the sound waves of your voice, except that the sound waves from your voice are more complex than those from a simple tuning fork.

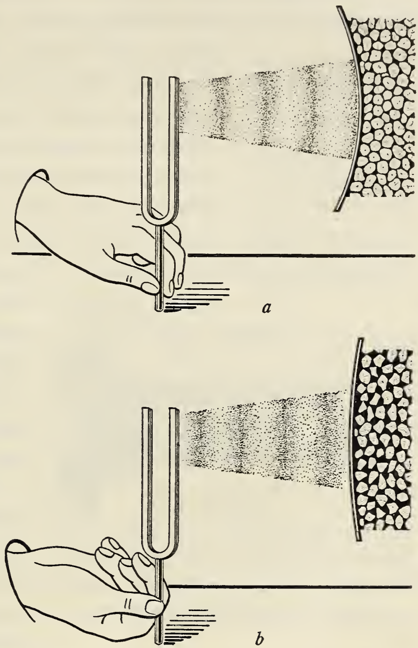


Fig. 311. The Vibration of the Diaphragm affects the Strength of the Current of Electricity flowing through the Circuit

Notice that in *a* a condensation striking the diaphragm has compressed the carbon particles, permitting a stronger current to flow through the circuit. When a rarefaction occurs in the sound wave, as in *b*, the reverse is true

Now let us look at the secondary circuit, beginning with the receiver itself. If you have ever unscrewed the cap from a telephone receiver, you have found an iron disk similar to the disk you saw in the transmitter. Underneath the disk, as you can see from Fig. 312, is a small horseshoe magnet. Since this is a permanent magnet, the two poles attract the iron disk at all times. Notice, however, that there are coils of wire around the poles of the magnet. The effect of these should be familiar to you.

As the current which flows in the secondary circuit varies, the strength of the magnetic field in the receiver also varies. Do you know why?

Look closely at Fig. 312. You see that the iron disk is supported by a thin metal ring in such a way that it can never quite touch the poles of the magnet. The iron disk in the receiver vibrates many times a second, to correspond to the vibrations set up in the transmitter. As a result, molecules in the air are made to vibrate, and a sound wave is set up by the receiver similar to the sound wave which caused the disk in the transmitter to vibrate. The sound waves reach the ear, and you hear the same sort of sound that was made by the voice of a speaker, even though he may be hundreds of miles away from you.

The variations in current produced in the transmitter circuit are repeated in the receiving circuit and affect the diaphragm in the receiver

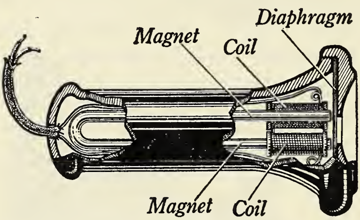


Fig. 312. The Receiver reproduces the Sounds produced at the Transmitter. The Effect of the Sound on the Transmitter is carried by Electricity

This circuit (Fig. 309) is far less complex than the circuits in use by the commercial telephone companies, where thousands of instruments may be joined together by thousands of miles of wire. Essentially, however, the principles of the telephone are simple, depending upon those properties of electricity and magnetism with which you are already familiar.

C. How does the Radio Work?

Of all electrical instruments the radio seems to many people the most mysterious. The mechanism of a nine-tube or eleven-tube radio is indeed complex. There are tubes and coils and wires of many kinds. Yet when this

mass of mechanism is attached to an aërial and plugged into an electric-light circuit, merely the turning of a dial brings in programs from all over the world.

The principles upon which a radio works, however, are not complex. As with the telephone, some of them are already familiar to you. It is their application which is a little more difficult. Yet the principles and their application can be explained so as to enable you to picture the working of your own radio the next time you turn it on.

Radio waves are a form of radiant energy

You remember from your previous work in science that energy may be carried through space as radiation. You recall that there are several forms of energy carried in this way. Light waves, for example, are one form of radiation. Radio waves are another. These waves differ in length, just as the sounds of high and low pitch do, but in some ways they are similar. Their true nature is unknown. It is obvious that they are not carried in the air, for waves of radiant energy travel even better in a vacuum than in air.

The nervous system is not sensitive to radio waves. They may be noticed only by the use of mechanical instruments. How are radio waves produced? How may they be made to carry the effects of sounds? How may the effects carried on the waves be translated into sounds like those producing the effects?

Radio waves are electromagnetic waves

Radio waves are really electromagnetic waves; that is, they are associated with the magnetism produced by electricity. How did anyone come to guess that there are such things as electromagnetic waves? The first guess was made by an Englishman named Maxwell. In working out some complex mathematical equations he came to the conclusion that his answers could only be explained if these waves were present. So he stated his guess. The work of Maxwell was followed by experiments made by a German named Hertz.

Hertz demonstrated that electromagnetic waves were given off as a spark jumped across the terminals of an induction coil similar to the one in Fig. 313. This instrument is of so much importance in electrical work that we must pause for a moment to examine it. In brief, an induction coil is a kind of transformer. A current of relatively low voltage and relatively high amperage is changed in an induction coil to one of high voltage and low amperage. How is this done? From a study of Fig. 313 the parts of an induction coil and its operation should be entirely clear. Notice that the primary, or battery, circuit is connected to an electromagnet made of relatively few turns of wire on an iron core. The secondary is a coil of a relatively large number of turns set so that it incloses the coil of the primary.

An induction coil is a kind of transformer

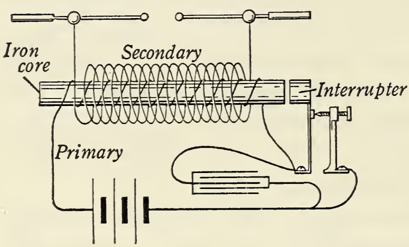


Fig. 313. The Principles of an Induction Coil help to explain the Operation of a Radio Set

After careful study of the diagram can you explain how electromagnetic waves are produced by the coil?

You know that, according to the electron theory, electrons in the secondary are made to flow in one direction when the primary circuit is closed and to flow in the opposite direction when the primary circuit is broken. The interrupter (shown in the figure) works like the armature of an electric bell. The interrupter is a piece of soft iron mounted on a steel spring. Current flows through the primary when the spring is in contact with the point of the screw. But when current flows, the iron core becomes a magnet and pulls the spring away from the screw. This breaks the circuit, the soft iron loses its magnetism, and the spring flies back against the

point of the screw. Again the circuit is made, and the process of make and break is repeated over and over. As the primary circuit is made and broken, an induced current flows first in one direction and then in the other in the secondary circuit. On account of the larger number of turns in the secondary the voltage is great enough to cause electrons to jump the gap between the terminals of the secondary.

The current in the secondary is a high-voltage alternating current

The condenser serves a useful purpose, for without it electrons would tend to jump the gap between the spring and the point of the screw when the interrupter is pulled away from the screw by the magnet. In this event there would not be a sharp break in the primary circuit. You may know that the sharper the break in the primary the stronger the voltage in the secondary. With the condenser in place the electrons do not jump this gap, but take a course offering less resistance and flow on to the condenser plates. As the contact is made again, they flow off the plates and continue in the circuit. The plates are charged as the circuit is broken, and they are discharged as the circuit is made.

Hertz observed that electricity flowing back and forth in the secondary of an induction coil would under certain conditions cause electricity to flow back and forth in another circuit that was in no way connected with the first. In other words, he demonstrated that energy was radiated into space when a current of electricity started to flow in a circuit and when it stopped flowing in a circuit. The sharp starts and stops of flow in an induction coil make this instrument a good one for demonstrating this effect. Since the waves have their origin in an effect caused by an electromagnet, they are called electromagnetic waves. This observation by Hertz was the beginning of radio.

The alternating current of the secondary gives off electromagnetic waves

These observations, made in 1888, suggested to men of an inventive turn of mind the possibilities of using electromagnetic waves for communication. Progress in the development of the radio has been progress in developing instruments for sending electromagnetic waves and instruments for receiving them. These instruments, as we know them today, consist of two essential parts: the transmitter and the receiver. As in the case of the telephone, let us look at them in their simplest form. Keep in mind, however, that the commercial sets involve a far more complex application of the principles we set forth.

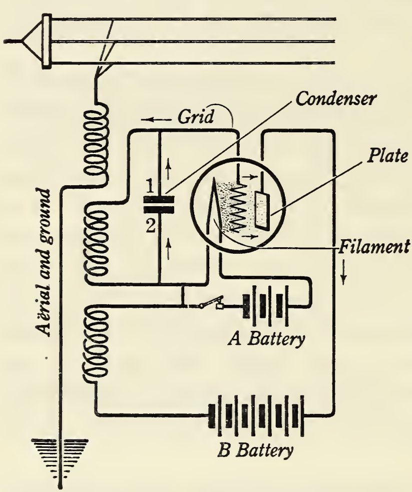


Fig. 314. A Simple Radio Hook-up

The essential features of radio are illustrated in this simple arrangement, which shows the main circuits

Consider first the transmitter, a wiring diagram of which is shown in Fig. 314. The essential features, as you can see, are a vacuum tube, *A* and *B* batteries, aërial, coils, and proper connections. By using the electron theory we may explain the function of all these parts. A photograph and a diagram of a vacuum tube are shown in Fig. 315. Inside the tube are three parts, called the filament, the grid, and the plate (Fig. 315, *b*). The names are descriptive of these parts. The filament is a wire which is part of the *A*-battery circuit. It enters the tube and leaves it again at the base. The

The vacuum tube is an important part of both transmission and reception in radio

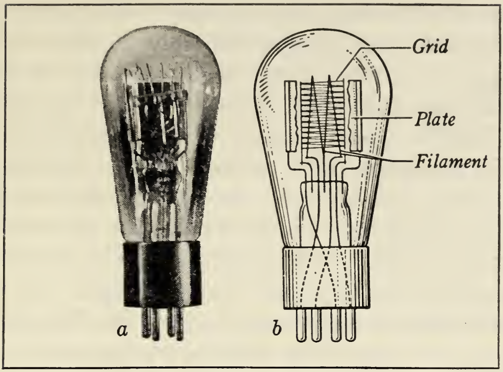


FIG. 315. A Photograph of a Vacuum Tube is shown in *a*. A Diagram is shown in *b*

Can you explain the part played in radio reception or transmission by the filament, by the grid, and by the plate? Try it again after you have read this section on the radio

plate is a solid piece of thin metal held upright in the tube by a piece of wire the end of which extends out at the bottom of the base. The grid is a netlike metal screen which fits between the filament and the plate. From it too a wire runs through the base of the tube.

Study Fig. 314 closely. Notice that two battery circuits are shown. These are indicated as the *A* circuit and the *B* circuit. In addition to these there is the grid circuit.

Look at these circuits. The positive and negative posts of the *A* battery are connected directly to the filament in the vacuum tube. The negative post of the *B* battery is connected to a circuit which feeds into the filament of the *A* circuit. The grid circuit is also joined to the filament. Notice that there is a coil in the *B* circuit and in the grid circuit. Notice, too, that there is a condenser in the grid circuit. This, as you will see later, serves as a storehouse for electricity.

Now examine the *B* circuit. Notice that while the positive post of this circuit is attached to the plate, the negative is attached to the filament. How, then, is it possible for a

current to flow through the *B* circuit? Obviously the electrons must pass over the gap between the filament and the plate. Electrons, however, are given off from the filament in the *A* circuit only while it is hot. When the *A* battery is put in circuit, electrons start to flow in the *B* circuit. The arrows in Fig. 314 indicate direction of electron flow.

Current flows through *B* circuit as electrons cross gap

Now in imagination let us watch this set work. First we close the switch. The current in the *A* circuit flows to the filament and back again. This is simple. As a matter of fact this current serves only to heat the filament. Thus when the *A* current is turned on, you see the filament glow. The important thing, however, is that when the filament becomes hot, electrons flow from it. Thus with a glowing filament you can imagine the vacuum tube filled with electrons moving in every direction. The positive charge on the plate of the *B* circuit causes electrons to flow from the filament to the plate and around the *B* circuit.

The *A* battery heats the filament, causing electrons to flow from it

How does the flow of electrons in the coil of the *B* circuit affect the flow of electrons in the coil in the grid circuit? From previous work you know that there will be an induced flow of electrons in the coil of the grid circuit. This induced flow alternates, while flow in the *B* circuit is always in the same direction. Do you see why? As electrons flow in the grid circuit from the grid, the grid becomes positive (it was neutral, but electrons leaving it make it positive). As it becomes more strongly positive, electrons, which are negative, are attracted from the filament. Remember that like charges attract and unlike charges repel each other. You can see that when the grid is positive, the flow of electrons from the filament to the plate is greater than the flow when the grid is negative or neutral. Thus the rate of flow in the *B* circuit increases as electrons are drawn away from the grid. But

The grid circuit acts as a regulator in the flow of electrons between the filament and the plate

notice that the grid circuit is not complete. Look at the condenser. Electrons moving away from the grid gather on condenser plate 2. Thus you see that electrons on the grid hinder the flow of electrons in the *B* circuit. Therefore the number of electrons flowing in the *B* circuit will increase as electrons flow away from the grid and decrease as electrons flow to the grid.

How long can the current continue to increase in the *B* circuit while the flow of electrons is away from the grid? Obviously not indefinitely. Soon the rate of flow reaches its highest point. As soon as current stops increasing, the induced current ceases to flow away from the grid. The electrons gather on plate 2 of the condenser. But as soon as flow toward plate 2 ceases, electrons begin to run off this plate and flow back toward the grid. Now the grid is becoming negative (it gains a surplus of electrons); and as it does, it slows down the flow of electrons from the filament toward the plate. This in turn reduces the current in the *B* circuit. (Can you explain why?) As this happens, a greater flow of electrons is induced in the grid circuit in the direction already started there. The grid becomes increasingly negative until finally the flow in the *B* circuit is at the slowest rate. Study Fig. 316. As soon as the flow stops decreasing, the induced current ceases to flow. Now, as you can see, electrons have gathered on the grid and on plate 1 of the condenser. When the pressure against them is released, they immediately start to flow away from the grid again, and away from plate 1 and toward plate 2 of the condenser. The grid once more becomes positive, and the current in the *B* circuit increases again. So it goes. Current increases in the *B* circuit until it reaches its highest point and then goes down until it reaches its lowest point. As it increases, there is an induced flow of electrons away from the grid; and as it goes down, there is an induced flow in the opposite direction.

Electrons in the grid circuit flow first in one direction and then in the other

This change about which it takes so long to tell takes place, of course, in a tiny fraction of a second. The change is called a cycle. The changes just described occur with every cycle. You may see in the newspaper that a station is broadcasting on 512 kilocycles (Kc.). One kilocycle is a thousand cycles. In this case the direction of the induced current is changing 512,000 times each second.

Each change of direction of electron flow in the grid is called a cycle

Adjoining the coil in the grid circuit is another coil. The terminals of this third coil are the aërial and the ground. You understand, of course, that electrons moving in one direction in the grid circuit will induce electrons to flow in the opposite direction in the aërial circuit.

All this may seem rather complex to you. Yet if you will study the diagrams carefully and follow in them the changing flow of current described in the text, we believe you can understand it. The important thing to remember is that with each change in direction of the aërial current an electromagnetic wave is sent off into space from the aërial, traveling with the speed of light. These electromagnetic waves are the carriers of radio communication. How does this affect a receiving set? The answer is simple. Electrons are made to flow back and forth in the aërial of a receiving set in just the same manner that they are moving back and forth in the aërial of the sending set.

Each cycle results in a wave of electromagnetic energy going off into space

Let us examine a receiving set. A diagram is shown as part of Fig. 316, *B*. In its main features it is just like the sending set. There are an aërial and a vacuum tube with *A*-battery, *B*-battery, and grid connections. As electrons flow back and forth in the aërial, they induce a flow of electrons in the grid circuit. Electrons flow toward the grid and slow down the flow of electrons across the

A receiving set is merely an instrument for changing electromagnetic waves into sound

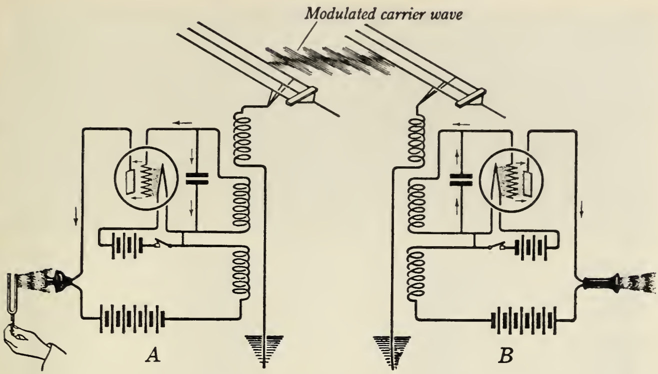


FIG. 316. Sending and Receiving in Radio

Electrons flowing through *A* are affected by the vibrating fork. The effect passes through space and may be detected in *B*. It is registered on the aërial, and affects the flow of electrons through the tube and finally the current through the telephone receiver

gap from filament to plate. Then they flow away from the grid and thus cause the flow of electrons across this gap to increase. The flow of electrons in the aërial of the receiving set regulates the flow of electrons in the *B* circuit.

You of course realize that under the conditions we have described all the waves are alike. Current in the *B* circuit is raised to its greatest point and reduced to its lowest point. Each change produces a wave cycle, and all the cycles are alike; that is, they have the same amplitude, or size, and they have the same frequency. Since these waves do not affect our sense organs directly, we may only guess what they are like. They are commonly represented in diagrams by the outline shown in *A* of Fig. 317. A line up or down represents one cycle, and the length of the line up and down represents the amplitude of the wave. This is called the carrier wave.

But how is music or the sound of the voice carried? Let us return to Fig. 316, in which a sending set and a receiving set are shown. Notice that a telephone transmitter is

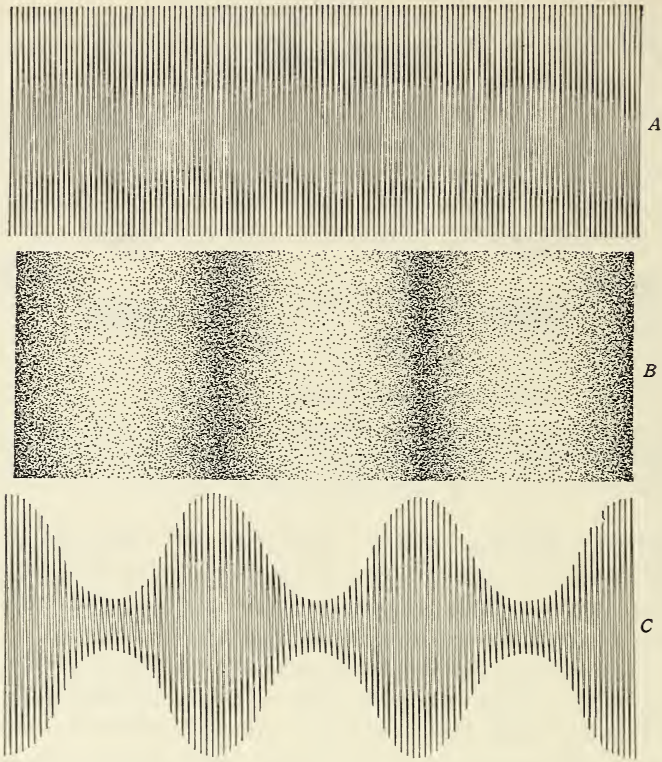


Fig. 317. The Normal Radio Carrier Wave is modulated by the Vibrations set up by the Voice or Other Sound in the Transmitter

A, the normal radio carrier wave; *B,* the cycles of rarefaction and condensation in a sound wave; *C,* the carrier wave in *A* as it is modulated by the sound wave in *B*

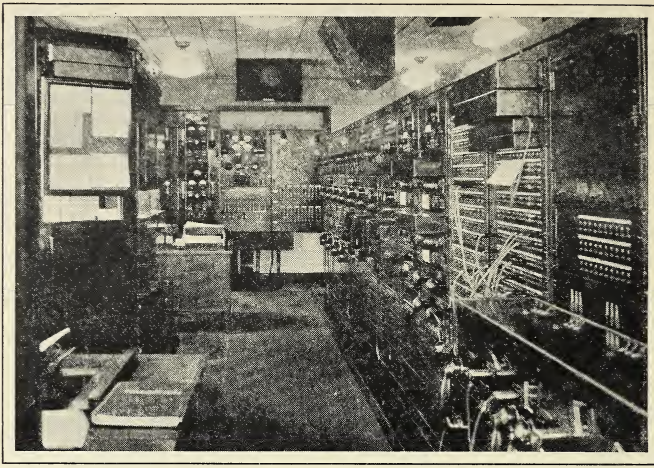
shown in the *B* circuit of the sending set. This serves as a microphone. When one speaks into the transmitter, the sound waves from the voice compress and release the carbon grains just as in the telephone. The strength of the current through the *B* circuit is now influenced by the voice, and this influences the amplitude of the wave.

As in the case of the telephone, let us use a tuning fork. It acts like the voice, and the effect is simpler. Suppose middle C is sounding before the transmitter. Two hundred and fifty-six condensations and rarefactions strike the metal disk each second. In other words, the carbon particles are compressed and released 256 times each second. Now suppose that the grid circuit is 512,000 cycles (512 Kc.) each second. Thus there are 2000 electromagnetic cycles for each cycle of a rarefaction and condensation in the sound wave ($512{,}000 \div 256 = 2000$). The effect of sound on the carrier wave is shown in *C* of Fig. 317. Here you see a carrier wave, still of 512 Kc., but with the amplitude, that is the size of the wave, changed by the effect of the sound wave. Let us explain the effect a little further. As the compression in the sound wave reaches the disk of the transmitter, there is least resistance in the *B* circuit. Thus the amplitude is at its greatest. As the condensation reaches the disk, there is most resistance in the *B* circuit, and the amplitude is at its lowest. You can point to these effects in Fig. 317. This effect on the carrier wave is called modulation. The carrier wave is modulated, or shaped, by the sound wave.

The microphone in a radio transmitter is similar to the transmitter of a telephone

The normal radio carrier wave is modulated by the vibrations set up by the voice or other sound in the transmitter

When the receiving set is tuned to the same frequency (512 Kc.) as the sending set, electrons are flowing back and forth in the grid circuit with the same frequency as in the grid circuit of the sending set. As the effect from waves of greatest amplitude comes in, the greatest amount of current flows in the *B* circuit and there is the greatest effect on the magnet in the telephone receiver. As waves of least amplitude come in, there is least effect on the *B* circuit and on the telephone receiver. This variation in the effect causes the disk in the telephone receiver to vibrate and produce the sound the influence of which was carried on the carrier wave.



Acme

Fig. 318. The Simple Principles of Radio you have observed in this Chapter are applied on a Large Scale in the Modern Broadcasting Station

Control room of station WABC. What do you think the telephone switchboard is for?

Follow these effects in the diagram of Fig. 316. The tuning fork produces sound. The sound produces an effect on the transmitter. This affects the *B* circuit and in turn the carrier wave, as shown. The carrier wave causes electrons to flow back and forth in the aërial of the receiving set with the same frequency as they flow in the aërial of the sending set. This sets up by induction a corresponding flow in the grid circuit, and this in turn carries to the *B* circuit and through the receiver the same effect as was produced on the transmitter of the sending set.

And now can you look at your own radio with perhaps a little more understanding? It of course has many extra parts not included in the simple set we have described. It has a tuning mechanism which enables you to shut out the effects of all waves except those from the station you want. It probably works on the house circuit instead of on the

battery circuit. Perhaps it has nine or eleven tubes. But essentially the principles upon which it works are the same as those we have just given. Similarly with the large sending stations. The one shown in Fig. 318 differs from the one we have described in that it is equipped to use larger amounts of electrical energy. Many improvements make the waves carry the effects of sounds more accurately. But even this large station is built upon the simple principles we have been discussing.

Sound is produced by vibrations which are carried in the air at a rate of about 1100 feet per second. It has three qualities: pitch, loudness, and quality. The telephone is based upon the principles of induced electrical currents the flow of which is affected by the condensations and rarefactions of sound waves. The radio is an instrument which changes energy of electromagnetic waves into sound. Electromagnetic waves are sent into space, carrying the effect of sound. As radiant energy they travel in space with the speed of light.

Can You Answer these Questions?

1. What similarities are there in the ways in which sound is produced by the vocal organs, stringed instruments, or a pipe organ?

2. What are the condensations and rarefactions in a sound wave and what relationship do they have to sound?

3. Is it correct to say that a radio wave is a sound wave? Can you defend your answer?

4. In terms of vibration, what determines pitch? loudness?

5. Can you trace the means by which the sound of the voice is recorded and reproduced in a phonograph?

6. What are the main features of a simple telephone circuit?

7. How are the effects of sound waves picked up by a telephone transmitter, carried as electrical energy, and transformed again through the receiver as sound?

T

8. What are the principles of the induction coil, and how are they applied in the radio?

9. What parts do the grid, the plate, and the filament of a vacuum tube play in radio?

10. What are the relationships between the *A* circuit, the *B* circuit, and the grid circuit in a sending set? in a receiving set? How do the aërial and ground wire affect these circuits? What part does the condenser play?

11. What is meant by the statement that a radio station sends on a certain frequency in kilocycles?

12. How does the normal radio carrier wave differ from the modulated wave? What produces the modulation? How does the sending set control the electric current so as to produce this effect?

Questions for Discussion

1. Why do most radios have to be "warmed up" before the program starts to come in?

2. Can you explain in scientific terms just what you do when you "tune in" a certain radio station?

3. What do you think are the essential differences between the "wireless" telegraph of Marconi and the radio of today? Consider principles, not small differences.

4. Musicians group musical instruments into these general classes: the percussion group, the wind group, and the string group. Does vibration enter into the production of sound by all instruments in each of these groups? Does it differ from group to group?

5. Can you think of any factors which might influence the quality of sound?

6. Would you agree that the telephone is a necessity rather than a luxury in our modern civilization?

7. In what respects is the vacuum-tube radio an improvement over the old crystal set?

8. How do you think the frequency of cycles is controlled in a receiving station?

9. What evidence can you present on both sides of this question, "Is radio a blessing or a curse in modern life?"

Here are Some Things You May Want to Do

1. Plan and take a trip to a radio broadcasting station or a telephone exchange. Be sure to decide just what you want to find out and the questions you want to ask, so that your trip will not be merely a sight-seeing one.

2. In England, radio listeners are taxed for their sets, and the money thus secured pays for the cost of programs. In this country the cost for the most part is paid for by advertising. Hold a class discussion on the relative merits of the two plans.

3. Make a large wall chart illustrating the simple sending and receiving radio circuits described in this chapter. The various circuits could be drawn in colored ink of a different color. Label your diagram, being sure to indicate the flow of electrons.

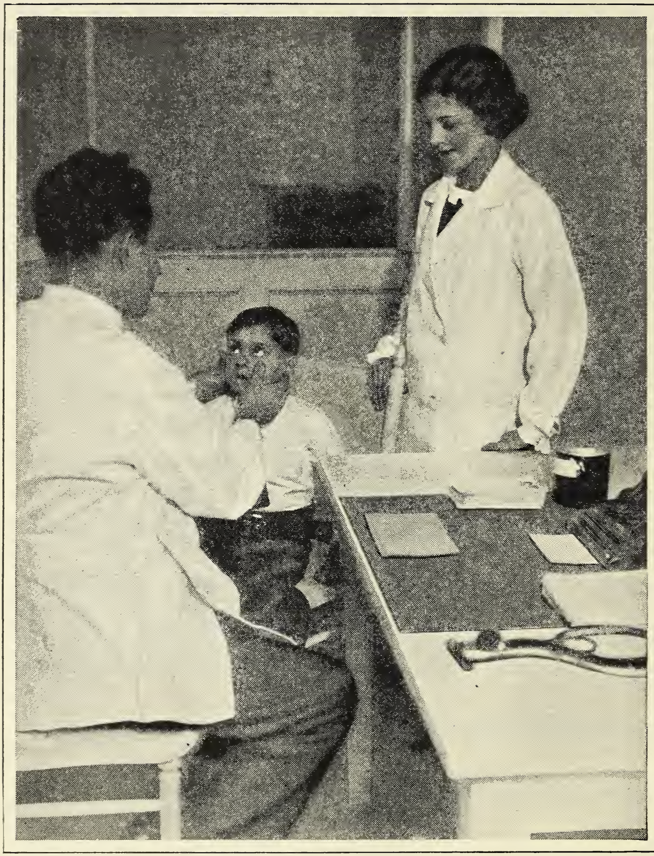


FIG. 319. Through the Careful Work of Public Health Officials Much has been done to improve Personal and Community Health

UNIT VI

How has Man gained an Increasing Control over the Conditions of the Environment which make for Healthful Living?

Chapter XXIV · How does a Healthy Human Organism Function?

Chapter XXV · What is the Work of the Nervous System in the Human Organism?

Chapter XXVI · What are the Causes of Illness, and How may we avoid Them?

Chapter XXVII · How does Man control the Condition of the Air Indoors?

Chapter XXVIII · How is the Health of the Community Controlled?

YOU HAVE by now studied many of the achievements through which man has gained control over features of his environment. In your study you have observed again and again the exercise of intellect. Driven by desires to understand and control the forces of the environment, man has developed new forms of plants and animals; he has learned to separate metals from ores and to make these metals into machines; and he has learned to harness the energy that flows over the earth and use it in many ways. In addition to these achievements in controlling his environment man has learned to interpret the changes in progress on the earth and the manner in which living things are adapted to these changes and he has learned to interpret the motions of the earth and other bodies of the universe as they move in space.

And now we may ask, What is the nature of man himself? How is he able to do all these things? These questions, like others, are more than we can answer, but we can learn many things about them.

What is it that, more than anything else, distinguishes man from other animals? The answers to this question may be summed up in one sentence. Through the use of his nervous system man is able to make things; and having made a thing, he is able to improve it. No other animal can do this.

In this Unit we turn our attention to the study of the functioning of the human organism. What is the general character of the nervous system? How do the muscles get power from food? What may we do as individuals and as members of a community toward keeping conditions favorable for normal functioning? In other words, how may we maintain our health and how may we maintain healthful conditions in our communities?

Chapter XXIV · How does a Healthy Human Organism Function?

What do you mean when you say a person is healthy? Is a person healthy just simply because he isn't sick? How sick does he have to be to be unhealthy? Is he healthy just as long as he can "get by" without a doctor? Are there differing degrees of health? Perhaps these questions suggest only a negative definition. A far better way to define health is to tell what it is, instead of what it is not. Can we find such a definition?

How does a healthy human organism function? Much of the work of this unit concerns the functioning of the human organism under healthful conditions. As a part of this story we must deal with the factors which disturb healthy functioning. Since all of this story makes constant reference to the bodily organism and its various parts, we must study a little more carefully how various parts of the body are adapted to special functions.

A. What are the Functions of the Skeleton?

You are doubtless familiar with the general make-up of the human skeleton. It is shown in Fig. 320. The total number of bones is slightly over two hundred. Some are large, and some are small. Many of them are connected through moving joints, and the bones are held together by strong ligaments. Observation shows that many bones of the skeleton function as levers. Recall what you learned about the simple lever, and apply it to the action in your arm when you pick up a book or a heavier object. Look again at Fig. 177 on page 332. If you will think of many similar actions, you can easily decide that one function of the skeleton is to help the body in motion. Notice the golfer

The bones of the skeleton act as levers

as he follows through in making a drive (Fig. 321). There is some motion at nearly every joint in his body. Even walking requires action of many muscles. Thus the skeleton can be seen as a combination of levers controlled by muscles in such a manner that we may direct our motions in many different ways.

The bones are held together by ligaments

Perhaps you have wondered how these bones are held together and made to move. The next time you have a leg of lamb for dinner examine it carefully after the meat has been removed. Notice the remains of the ligament that held the bones together. If you wish to study this even more closely, boil the bone in strong salt water for fifteen minutes. Now the ligaments come loose from the bone, and you can see clearly how the bones are fitted together. Have you ever heard of anyone's having an accident in which he threw a bone out of joint? What do you think this means? A very severe strain may cause such an accident.

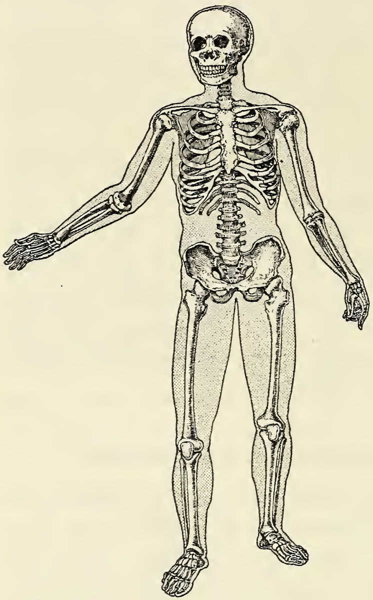


FIG. 320. The Bones of the Skeleton Act as Levers

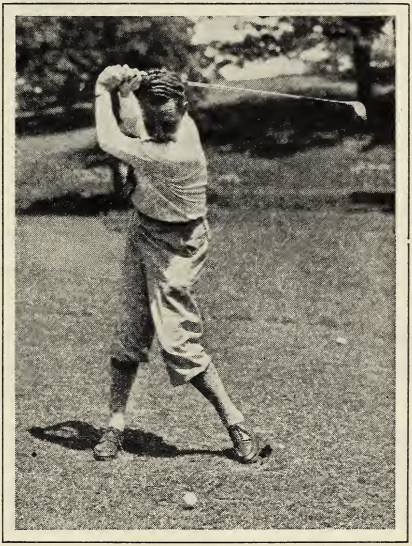
How many levers of the three types can you find in this skeleton?

If you could look at the bones of your own skeleton as closely as this, you would see that they are fitted together in much the same way as are the bones of the leg of lamb. As you sit on a chair, observe how easy it is for you to swing

your legs back and forth. How is this possible? Study Fig. 322, which shows (*a*) an X ray of the knee joint and (*b*) the tendons and ligaments of the leg. Notice that the joints are bound together by ligaments and that the muscles are attached through tendons. Notice, too, how the enlargement of the bones at the end allows space for these attachments. Ligaments and tendons are very strong.

The muscles which move the bones are usually attached by means of tendons

You may understand from Fig. 322 what happens when you strain your knee through an injury to one or more of these attachments. What should you do when you suffer a strain? Obviously the injury will grow worse if you continue to use the knee. Therefore recovery will be quickest if you keep the knee still. If the strain is quite serious, it may be necessary to set the joint in a cast so that you cannot move it until there has been time for the injury to repair itself.



Ewing Galloway

Fig. 321. In Some Forms of Physical Action there is Motion at Nearly Every Joint in the Body

This golfer has been said to have perfect bodily coördination. What do you think this means?

You may think of bone as hard and unbending. But, as you may know, the bones of a child are not so hard as the bones of an adult. At birth the bones are flexible (that is, they will bend), and the joints move with greater freedom. A child is often twelve

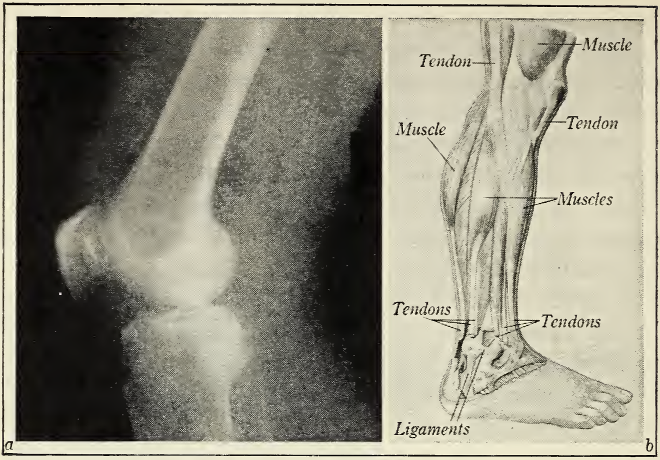


FIG. 322. The Bones of the Skeleton are closely fitted together, and are held together by Ligaments

a, an X ray of the knee joint; *b*, some of the tendons and ligaments of the leg

months old or more before he is able to stand upright. Evidently the bones of the body harden as the child develops.

In their early stages the bones are composed of tough, elastic tissue. The chemical elements necessary for growth and development are fed to the bones through the blood. Compounds, of which calcium phosphate and calcium carbonate are in greatest abundance, deposit in the bones, causing them to harden. You may recall from previous study that vitamin D is essential to healthy growth of the bones. If there is insufficient vitamin D in the diet, these minerals do not deposit properly and healthy bones do not form.

Bones are composed of compounds of chemical elements

The bones harden as they grow larger. The hardening continues through the period of childhood and into adult life. This gradual development helps to explain why a child can experience without harm falls which would result in serious physical injury to an older person.

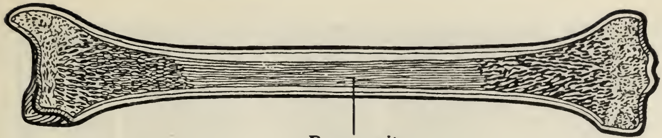


Fig. 323. The Bones of the Body are Hollow

Would a bone such as this look different in an old person from the way it looked in the person's childhood?

It is easy to remove most of the mineral compounds from a bone, for they are soluble in acid. Place a chicken bone (the "drumstick," for example) in some strong vinegar or in some dilute hydrochloric acid and leave it until the bone has softened so that it will bend without breaking. If you wish, you may evaporate the acid solution and obtain some of the "minerals."

If you cut with a knife this softened bone, you see at once that the bone is hollow. Fig. 323 shows a section of the long bone of the human leg. It too is hollow. In childhood this hollow space is partly filled with a spongy bone tissue which slowly disappears with advancing age. There is bone marrow in the hollow space. This marrow functions in connection with providing the bone with nourishment. It also functions in another important respect, which at this time need only be mentioned. Red blood cells are manufactured in the bone marrow.

A broken bone is a sad reminder of the function of the bones in the body. Without them we are powerless to stand upright. However, our bones do have remarkable power to restore themselves. Fig. 324 shows an X ray of a broken bone, shows how it was set, and how it appeared after healing. If you could follow the process closely, you would see that the broken ends begin to form new cells. A tissue like that of the bones in a very young child forms across the gap and slowly hardens. The manner in which this new growth occurs is

Broken bones repair themselves

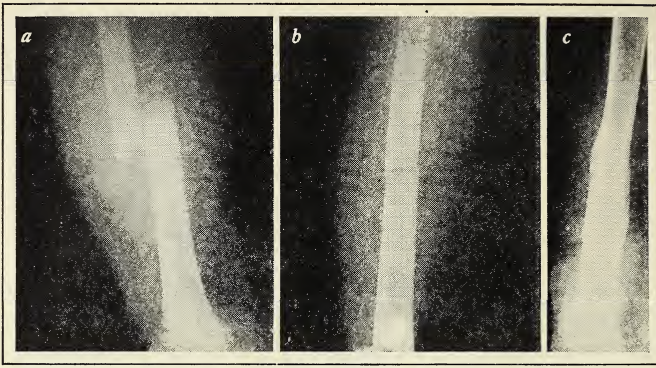


FIG. 324. With Proper Care Broken Bones repair Themselves

a, X ray of a broken leg; *b,* the bone after being properly set; *c,* the leg after the bone has knitted properly

similar to the manner in which the soft bone of an infant changes to the hard bone of an adult except that, in healing, the changes go on much faster. During the process of healing, the bone must be carefully protected, and for this reason it is set in a cast. After healing is complete, the bone is as strong as ever.

B. What Part do Muscles play in the Functioning of the Body?

The most obvious muscles are those attached to the skeleton. You may feel your own muscles as they tighten and relax, or loosen. While these skeletal muscles are most in evidence, there are others quite unlike the skeletal muscles in both structure and function. There is the diaphragm, a sheet of muscle separating the chest and the abdomen. This sheet of muscle, shown in Fig. 325, serves an important function in breathing. There are muscles in the walls of the arteries; you may feel their action as you count your pulse. There are other muscles in the walls of the esophagus, the stomach, and the intestine. In addition

to these muscles and others that resemble them in structure and function, there is the heart muscle.

On the basis of structure and function there are three different kinds of muscles: (1) striated and voluntary (skeletal muscle); (2) smooth and involuntary (muscles of diaphragm, stomach, intestine, and others); (3) striated and involuntary (heart muscle). The lean meat of pork or beef is striated muscle.

There are three types of muscles

We say that the skeletal muscles are striated and voluntary. What does this mean? *Striated* is a word which means "striped," and when used for the description of a muscle refers to its appearance. You see striated muscles when you eat lean meat. Boiled muscle tissue may be easily separated into muscle fibers, and by close examination you may see the stripes on the separated fibers. Fig. 326 shows the appearance of smooth and striated muscles when seen through a microscope. But why are the skeletal muscles called voluntary? It is because they may be controlled by thought processes. You will learn more about this later.

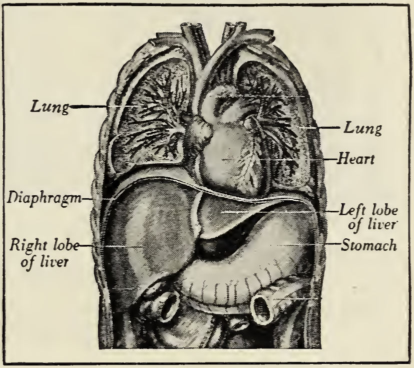


Fig. 325. The Muscle Sheet of the Diaphragm serves an Important Function in Breathing

In contrast, the smooth muscles work without voluntary control. You cannot by conscious effort affect the action of the muscles in the walls of the intestine. Neither can you consciously increase or decrease the rate of your pulse. You may, however, hold your breath for a short time, and thus may consciously increase or decrease the rate of breathing.

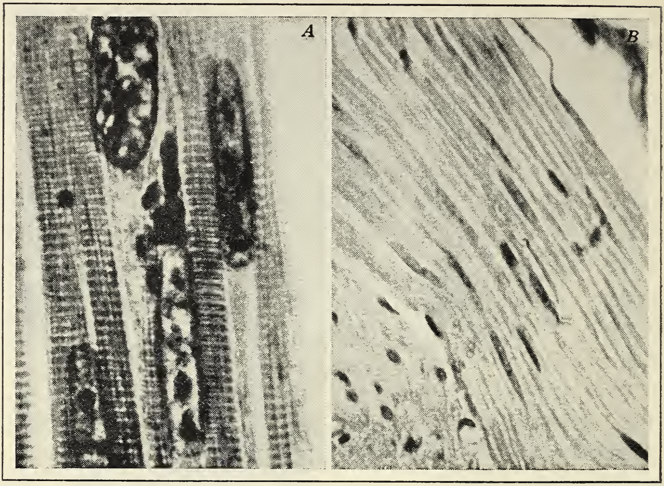


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FIG. 326. In Structure there are Two Types of Muscle: the Striated (*A*) and the Smooth (*B*)

The pictures above are microphotographs of tissue from each of these types. Which one does the cardiac muscle resemble?

But normally you breathe without thinking about it. This leaves us with the last type, heart muscle. There is no other like it, for it shows striations and is also involuntary.

Energy of foods is released in the muscles

The muscles are of importance for several reasons. You know of course that they furnish the power by which motion is made possible. But they are important in other ways. It is in the muscles that the energy of food is released. You know some things about the changes that go on as muscles are exercised. Foods and oxygen are dissolved in the blood and are distributed to the muscles. The solution seeps through the walls of the capillaries, as the small blood vessels connecting the arteries and veins are called, and the muscle cells are bathed in the nourishing liquid. Chemical changes take place as energy is released. Under normal conditions simple sugars are oxidized, and energy in the

foods is changed into energy of heat and mechanical motion. The expression for this chemical change you have seen before:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O}$$

The changes are really not so simple as seem to be suggested by this expression. The rate at which energy is released by this chemical change is limited by the rate at which oxygen can be taken into the lungs. Let us study this relationship.

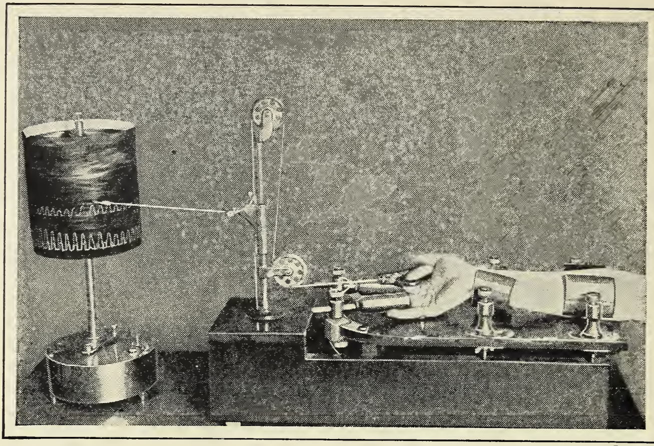
C. How do the Muscles function during Vigorous Exercise?

The best way to introduce this problem is to consider a particular form of such exercise. Let us look at an athlete in a 440-yard dash, which is considered by many the most taxing of all track events. The world's record is 47.4 seconds. Our runner was not quite so fast as this, but he was a good athlete.

Vigorous exercise causes an "oxygen debt" which must be paid before normal functioning is resumed

Observations taken of this athlete show that, starting from rest, he ran 440 yards in 1 minute. During this interval he did not take in enough oxygen, for at the end of the race he was out of breath. Careful observations show that the energy requirements of his body during this race were equal to the amount that might be released in oxidation by 15.8 quarts of oxygen. Yet the runner could not take in more than 1.8 quarts dur-the race (1 minute). In other words, the athlete developed an "oxygen debt" of 14 quarts. Heavy breathing continued following the race until this oxygen debt was repaid. We shall come back to this a little later.

What goes on in the muscles of the runner while this oxygen debt is developing? Examination of a healthy muscle shows that considerable food is stored in it. You know something of how glycogen is stored in the liver. It



Phinny

FIG. 327. The Rate of Muscle Fatigue may be Determined Very Accurately

The machine shown here is called an ergograph. Of what value do you think such records are?

is stored in the muscles also. In a healthy muscle there is enough stored to supply energy for a considerable time.

Muscle fatigue is accompanied by the formation of lactic acid

As the muscle is exercised, some of the glycogen is changed to glucose, and this in turn is changed to lactic acid. In these changes energy is released, which supplies force to the muscle. The release of lactic acid interferes with the action of the muscles. It is, in fact, the major cause of fatigue. The muscle recovers from fatigue as the extra supply of lactic acid is cleared away.

Examine a muscle in action. Suppose you were to attach your finger to a machine like the one shown in Fig. 327. The blackened drum is run by clockwork so that it moves at a uniform rate. While your finger is still, the needle traces a straight line; but as the finger is moved, the needle moves up and down. In one experiment a load of 3 kilograms (6.6 pounds) was attached to the middle finger and raised at intervals of every two seconds. The

needle registered on the drum the character of each contraction. The observations were continued through forty-six contractions, coming at the rate of one every two seconds. The record is shown in Fig. 328. Notice that the first contraction is long and vigorous. But study the record more closely. The force of the contractions decreased rather rapidly through the first twenty seconds, then more slowly through the next forty seconds. Through the next thirty-six seconds the force of the contractions fell off rapidly until the failure of the muscle was nearly complete.

Muscle fatigue increases as work continues

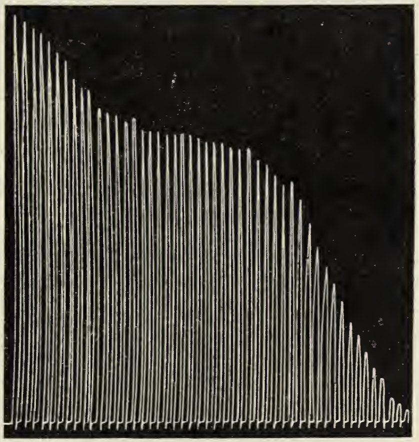


FIG. 328. Muscle Fatigue increases as Work Continues

This record was made with a machine similar to that in Fig. 327

What was going on in the muscle cells? Only a partial answer can be given. It is certain that lactic acid was collecting. This indicates that there is a need for oxygen. At the end the need for oxygen is so great that the muscle cannot function. As the finger was rested, however, certain other chemical changes took place. The lactic acid was cleared away, and the muscle was again in condition to function normally.

Now let us come back again to our problem of oxygen debt. In violent exercise, such as racing, the muscles of the body are fatigued in much the same way as the muscles of the finger are fatigued in this experiment. A runner moving with all the speed he has must stop in a few minutes for

rest. In a race of 100 yards a runner finished in $10\frac{4}{5}$ seconds. This is at the rate of about 9.2 yards in 1 second. At the end he was thoroughly exhausted and panting furiously for oxygen. Careful studies showed that the oxygen required to produce the energy used in this race was about $5\frac{1}{2}$ quarts. This was determined, as described below, by measuring the amount of oxygen required for recovery after the race. Five and one-half quarts in $10\frac{4}{5}$ seconds is at the rate of about 30 quarts a minute. This demand, of course, is many times greater than the lungs and circulation can supply. Therefore during racing an oxygen debt collects that must be repaid during rest.

As 1 quart of oxygen reacts chemically with glucose, about 5 kilogram-calories of heat energy are produced.

The energy used in exercise may be accurately measured

You may recall from earlier work that 1 kilogram-calorie is equivalent to about 3000 foot-pounds. Five kilogram-calories are equivalent to 15,000 foot-pounds of energy. During the race the runner was using energy at the rate of 450,000 foot-pounds per minute, or at the rate of more than 13 horsepower $\left(\frac{30 \times 15{,}000}{33{,}000} = 13.6+\right)$. No human being could work at this rate for more than a few seconds at a time.

The oxygen debt which may be carried varies with different people and is fairly constant for the same person. A measure of the oxygen debt in a particular person is taken by measuring the amount of oxygen used during normal breathing and the amount used during heavy breathing following a period of exercise. In this experiment the athlete breathes through a gas meter which measures the amount of air entering his lungs. Air from the lungs is collected in a large bag. Chemical examination of the air in the bag will show the amount of oxygen taken from it. The measurements are continued after the experiment until breathing is at a normal rate. The method used is shown in Fig. 329. The difference between the amount of oxygen

FIG. 329. The Oxygen Debt acquired during Vigorous Exercise may also be measured Very Accurately

After reading the text see if you can explain the method of measurement shown here[1]

used during rest and the amount used during heavy breathing following exercise is a measure of the oxygen debt acquired while exercising. The athlete who can show greatest endurance has the ability to carry the greatest oxygen debt.

Careful studies of the runner referred to above show that he may continue to exercise until his oxygen debt, that is, the amount of oxygen required to restore his muscles to normal condition, is as much as 14 quarts. His greatest oxygen intake from breathing air is about 12 quarts in four minutes. This racer may do in four minutes the amount of work equivalent to that done by breathing 26 quarts of oxygen ($14 + 12 = 26$). Since 1 quart is equivalent to 15,000 foot-pounds, this is at the rate of 390,000 foot-pounds in four minutes, or 97,500 foot-pounds in one minute. This is at the rate of nearly 3 horsepower. In other words, the runner who worked at the rate of more than 13 horsepower for ten seconds can work at the rate of less than 3 horsepower for four minutes. As he continues,

[1] From Hill's *Living Machinery*. By permission of Harcourt, Brace and Company.

the rate at which he can work becomes slower. An average strong man can work through the day at the rate of about $\frac{1}{7}$ horsepower.

To summarize this section, we may say that there is a definite limit to the rate at which oxygen can be taken into the body. If the demand for oxygen is greater than can be supplied, as it is during vigorous exercise, an oxygen debt develops. This oxygen debt is repaid by rapid breathing, which continues after the vigorous exercise has ceased.

D. What are the Effects of Exercise?

Exercise makes demands upon all organs of the body

There are obvious effects produced by exercise. A foot race or even a brisk walk brings an increase in the rate of breathing. Energy is released from the foods at a more rapid rate. Therefore more oxygen and more foods are demanded by the cells. There is an increase in the rate of heartbeat, and the body as a whole responds to the demands arising in the muscle cells as they are exercised. Certainly the body is affected by exercise. Study the effects of exercise on the heart by comparing its action before and after vigorous exercise.

First of all, let us look at the heart itself. Imagine the blood stream as it flows back toward the heart through a system of veins. These combine near the heart into two large veins called the superior vena cava and the inferior vena cava (Fig. 330). These veins in turn enter the upper right-hand chamber of the heart (called the right auricle). As the heart beats, the blood flows from the auricle into the lower right-hand chamber, called the right ventricle. The heartbeat continues, and the blood is pumped from the right ventricle into the pulmonary artery, which carries it into the lungs. Here, as you have learned, it gets a new supply of oxygen. On its return journey it flows back through the pulmonary vein into the upper left-hand

chamber of the heart, called the left auricle, and from there into the lower left-hand chamber, called the left ventricle. It now leaves the heart through the principal artery, called the aorta, and thus runs a cycle.

From the foregoing description you can see that the ventricles (right and left), shown in Fig. 330, are the chambers from which blood is pumped. As the strong muscles contract, the blood is forced out of the ventricles, producing a sound described by medical students as "lubb." As the muscles relax, a valve closes to prevent the blood from flowing directly back into the ventricle. The sound produced by the valve as it closes is described as "dup." The two sounds "lubb-dup" make one heartbeat. Normally the rate of heartbeat in a healthy person is about seventy times a minute. The rate is faster in children than it is in adults.

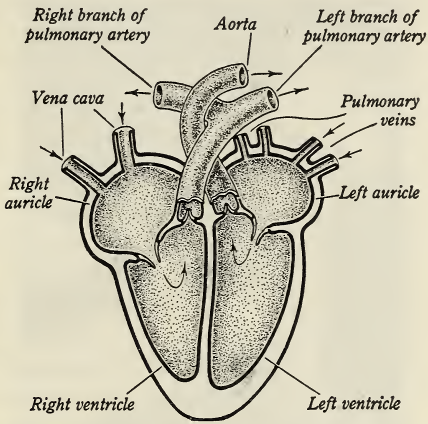


Fig. 330. Blood enters the Auricles and leaves from the Ventricles

This diagram shows a cross section of the heart. From it can you explain how blood reaches the heart and leaves it again? What part do the valves play?

The amount of blood flowing through the heart is fairly large, about 1 gallon in a minute. This is 60 gallons in an hour, 1440 gallons a day, and 34,164,000 gallons in sixty-five years. The heart is really a busy organ.

The heart pumps large quantities of blood through the body

The force with which blood leaves the heart is called the blood pressure. This may be measured with an instrument like the one shown in Fig. 331. This

is called a sphygmomanometer (*sphygmo* is derived from a Greek word meaning "pulse"). You have probably had your blood pressure taken. A rubber bag is strapped about the arm. Air is forced into the bag with a small hand pump. A tube from the bag is attached to a mercury gauge, which measures the air pressure within the bag. As more air is forced into the rubber bag, the pressure on the arm increases. In a little while it is great enough to close the arteries and stop the flow of blood into the arm.

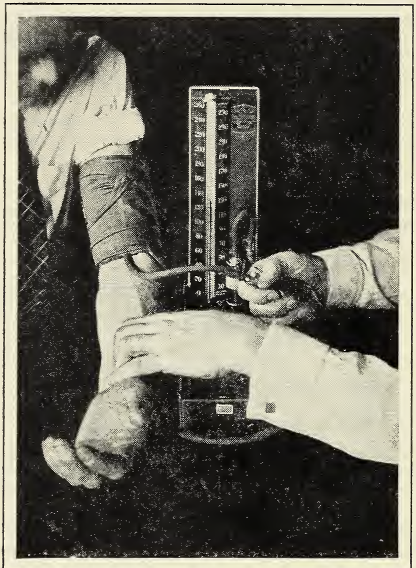


Fig. 331. Blood Pressure is a Measure of the Force required to drive the Blood through the Body

Can you explain the method illustrated here? Why is a doctor interested in the blood pressure of an adult?

When the physician is taking your blood pressure, he places his fingers over the large artery in the arm, between the bag and your hand, as shown in Fig. 331, and feels your pulse. In this manner he can feel the blood flowing through the artery and he can determine the pressure which is just sufficient to stop the flow into this artery. The pressure of the air in the bag against your arm is just the same as the pressure supporting the mercury in the tube.

Your physician may tell you that your blood pressure is 116. This is normal for fifteen-year-old boys (110 is

normal for fifteen-year-old girls). The physician means by this that your blood pressure is a force sufficient to support a column of mercury to a height of 116 millimeters. This is equal to about 4.5 inches. Since mercury is 13.6 times heavier than water, your blood pressure is sufficient to support a column of water about 60 inches, or 5 feet, high $(4.5 \times 13.6 = 61.2)$.

Blood pressure is a measure of the force required to drive the blood through the body

How much work is done by your heart in one hour while you are at rest? The density of the blood is about the same as the density of water. One gallon weighs about 8 pounds. Blood flows through the heart at the rate of about 1 gallon (8 pounds) a minute and with force enough to raise it to a height of 5 feet. The work done in one minute is therefore sufficient to raise 8 pounds of blood a distance of 5 feet. This is 40 foot-pounds, a little more than $\frac{1}{1000}$ horsepower.

But what happens during exercise? During a hard race the heartbeat increases enormously. At the end of a quarter of a mile it may be working at the rate of 140 beats or even faster. The blood pressure remains about the same, and about the same amount of blood passes through the heart with each beat. But with the increased heartbeat under these severe conditions about 2 gallons of blood pass through the heart each minute. The heart is now working at the rate of 80 foot-pounds a minute. Obviously there is a limit to the rate at which the heart can work. This varies at different ages and in different people. For healthy high-school boys the limit is about 150 beats a minute.

Exercise affects the amount of work done by the heart

While resting you may breathe sixteen times in a minute and in this time take into the blood about 1 pint of oxygen. As you walk, however, the rate increases. In one observation of a man walking at the rate of 5 miles per hour oxygen was used at the rate of $4\frac{1}{2}$ pints per minute, or $4\frac{1}{2}$ times the amount used while at rest. In order to supply this amount

Exercise affects the amount of oxygen used by the body

of oxygen the person breathed deeper and faster. Muscles in his chest and air sacs in his lungs were exercised more vigorously as a result of walking.

The amount of food eaten and the amount of energy released may be measured. You have already learned that the rate of energy release is increased enormously during vigorous exercise. The person walking at the rate of 5 miles an hour found that he used $3\frac{1}{2}$ pints more of oxygen each minute while walking than when at rest. Since oxygen supplies energy at the rate of about 5 kilogram-calories a quart, this is enough to supply nearly 9 kilogram-calories of heat ($3\frac{1}{2} \times 2\frac{1}{2} = 8\frac{3}{4}$). A rate of 5 miles in one hour is the same as 1 mile in twelve minutes. In this interval he would release about 108 kilogram-calories of energy ($9 \times 12 = 108$). Suppose the man weighs 70 kilograms (70 kilograms = 154 pounds). This amount of energy converted into heat would raise the temperature of his body about 1.5° C. ($108 \div 70 = 1.5+$). The liberation of this amount of heat in the body would raise the temperature of the body and produce fever if other changes did not occur to prevent it. You know that perspiration flows more freely during exercise and that this serves as an aid to control of temperature.

Fig. 332. The Valves found in the Veins of the Body control the Direction of Blood Flow

Exercise affects the temperature of the body

There is also an effect from exercise on the process of getting rid of waste products. The pressure of the muscles as they contract and relax forces the blood through the capillaries and veins toward the heart. Valves (Fig. 332) control the direction of flow. More wastes are produced under the conditions of exercise. Therefore the quantity of waste removed from the blood through the kidneys is increased.

Acme

FIG. 333. There is Enjoyment in Watching Games of Skill
What do you think has just happened?

Studies which have been made seem to indicate that every organ of the body is affected directly or indirectly by exercise. For the time being, however, the facts stated above are sufficient to show that exercise does affect bodily functioning. At a later time you may learn more about this.

E. How Much Exercise is Necessary for Good Health?

Many people at different times have advanced many arguments for the value of exercise. Yet probably the most important reason for taking exercise is because we like it. There is a healthy interest in play and in clean competition in athletics. Every person seems to enjoy doing some things well. The desire to excel helps to make a good player, whether it be of tennis, baseball, golf, or some other line of physical activity. Participation in some form of physical activity makes for happiness and wholesomeness in life. A major aim in exercise is to gain enough skill to enable you to hold your own in competition with your friends.

Exercise has a valuable mental effect upon people

Among all peoples there seems to be a keen interest in watching games of competition. Interest, as shown in Fig. 333, is probably keenest among those who have at some time participated in the sport. Thousands of spectators view games and get satisfaction from watching the players perform feats which the observers themselves at some time have done or tried to do.

For health one should exercise sufficiently to keep himself fit and able to participate directly in some form of outdoor sport. Then, too, one should participate sufficiently in sports to enable him to appreciate some of the fine points of popular games. The result is the development of wholesome interests which will probably be lifelong.

Wide World

Fig. 334. This Boy and this Girl have just won First Prize in a Health Contest

Can you now describe a healthy human organism? Have you learned anything that would help you in the application of the definition given at the beginning of this chapter? Perhaps all one can say is that it is difficult indeed to distinguish by definition between the functioning of a healthy organism and that of one not so healthy. It is difficult to say what health is, but we can usually recognize it. A condition of health is illustrated in Fig. 334. We should recognize, however, that certain factors, such as pure food, sufficient rest, fresh air and sunshine, and a moderate amount of exercise, are very important in maintaining good health. The requirements for good health are generally the things we like to have and to do.

The health of the human organism must be considered in terms of three factors, physical, mental, and social. The principal structure of the body consists of bones covered by masses of muscles which supply the force necessary for the movement of the bones. Energy is released in the muscles by the oxidation of foods carried in the blood stream. Under certain conditions muscles are fatigued and lose their power to supply force. At such times the human organism must rest.

Can You Answer these Questions?

1. What changes take place in the bones of a person as he or she becomes older?

2. How are the bones of the body held together?

3. What are the various types of muscles? What part does each play in the normal functioning of the body?

4. What is meant by "oxygen debt"? How is it acquired? How is it repaid?

5. What is the explanation for muscle fatigue? How does this account for the increasing inability of a muscle to do continuous work without rest? How does it help to point out the proper methods of rest?

6. How is it possible to measure accurately the energy used in exercise? to measure the horsepower generated by a living organism in working?

7. Can you trace the course of the blood stream through the body from the time it leaves the heart until the time it returns?

8. What is meant by the blood pressure? How is it measured?

9. Why does not the temperature of the body increase during exercise?

10. Is it possible to say how much exercise is necessary for good health? What standards for measurement might be set?

11. How much blood flows through the heart in a day?

Questions for Discussion

1. How would you define a really healthy human organism?

2. How many examples of the various types of levers can you find in the human body?

3. Have you ever heard anyone referred to as muscle-bound? What do you think is meant?

4. Have you ever heard a runner in a long race say he was perfectly all right as soon as he got his second wind? What do you think this means?

5. Why do you think a quarter-mile race is considered the most trying on a runner? Answer if you can in terms of oxygen debt.

6. Does blood pressure increase or decrease as a person becomes older? Why do you think this happens?

7. Which do you think the most interesting form of athletics from the standpoint of a player? of a spectator?

Here are Some Things You May Want to Do

1. You can check on some of the effects of exercise upon your own body if you will record your own pulse and respiration directly before and directly after taking part in some athletic event. What changes took place? Can you explain them? What effect did they have upon other bodily processes?

2. Make a wall-chart or diagram of the heart and lungs, showing how blood circulates through them.

3. Look up records for some athletic event such as the quarter-mile or mile run and see how man has gradually run these races in faster and faster time. What has made this possible? Is man developing physically, or is he using his physical ability to better advantage?

4. Prepare a set of standards which might be considered in determining whether or not a human organism is a healthy one.

Chapter XXV · What is the Work of the Nervous System in the Human Organism?

Have you ever held your finger near a hot object and pulled it away quickly as you felt the heat? Have you ever stopped suddenly in the middle of the street as you heard the sharp sound of an automobile horn? Have you ever been walking along with a group of other boys or girls, seen a glittering object on the path ahead of you, and dashed quickly to pick it up before any other person in the group could reach it? All these are simple experiences. In all of them your bones functioned as they were moved by your muscles. But why did your muscles move? What power or force caused the muscles of your hand, for example, so to move the bones of your hand as to pull the hand away from the hot object? The answer to these questions may be found in a study of the nervous system.

The nervous system consists of two main divisions

What is the nervous system, and how does it function? It is commonly thought of as having two main divisions, called the autonomic (*auto* comes from a Greek word meaning "action upon or within self") and the cerebrospinal (*cerebro* refers to the brain, and *spinal* to the spinal cord). The meanings of these two words may become clearer through a consideration of these two divisions of the nervous system and the part each plays in the functioning of the human organism.

A. What is the Cerebrospinal System?

This system is shown in rather simple form in Fig. 335. Notice three things: first, the brain; second, the spinal cord; and third, the many nerves which run to all parts of the body. From this you may think of the cerebrospinal system as one made up of nerves, in all parts of the body,

which run into the spinal cord and finally into the brain. Put very simply, this is true. But the whole story is far more complex than this. If you could look closely at the spinal cord (Fig. 336), you would see that it consists of a mass of gray and white matter. Close examination would show that the gray matter is composed of countless nerve cells, while the white matter consists of nerve fibers.

The cerebrospinal system consists of the brain, the spinal cord, and many nerves

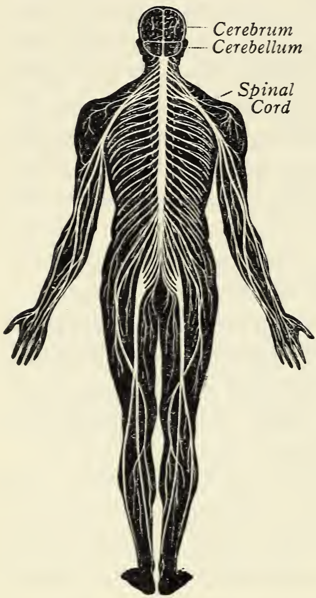


Fig. 335. The Cerebrospinal Nervous System is made up of the Brain, the Spinal Cord, and a Network of Nerves

This system directs voluntary action

You will learn more about their function later. You should know that these fibers branch off all along the spine to form the nerve connections to all parts of the body. Perhaps you can imagine the complex nature of this system if you will see it as a vast telephone system with means for receiving and sending messages at almost every point on and in the body.

While we shall have more to say about this system later, the main point to remember here is that the nerves which compose the cerebrospinal system are those which direct voluntary action, or, in other words, action by the will of the individual. Stated in another way, the nerves of the cerebrospinal system are the nerves that control conscious action.

But how is this accomplished? Consider the system as consisting of three main parts. First, there are the receiving

organs. They are sensitive to stimuli; that is, they respond to effects which produce sensations. Second, there are the connecting organs. As the name suggests, they form a connecting link between the receiving organs and the organs which finally react, or respond, to the original stimuli. Third, there are the reacting organs. They carry on activity as the result of stimuli. A common example, of course, is a muscle. Let us now consider the relationships of these various parts to each other.

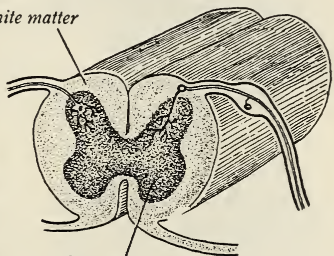


Fig. 336. The Spinal Cord consists of a Mass of Nerve Cells and Nerve Fibers

The receiving organs consist primarily of millions upon millions of so-called receptors, or small sense organs, which are located in all parts of the body. These receptors are alike in that each of them is connected to a nerve which carries to the connecting organs the impulse received from the stimulus. They are unlike in that groups of them react to different stimuli. What does this mean? Simply that some of these receptors react to touch, others to sound, others to sight, and still others to other stimuli. Each group is specialized for its particular function. Let us describe these groups.

Various sense organs receive stimuli from various parts of the body

1. *The tactile receptors found in the skin, the muscles, and certain other organs.* Some different types are shown in Fig. 337. They are sensitive to many things. Some react to pain, some to pressure, and still others are sensitive to muscular motion. Two other groups react to heat and cold. These are distributed all over the body, directly under the skin, forming areas called hot and cold spots, which are especially sensitive to the sensations caused

The tactile receptors are sensitive to touch, pain, heat, and cold

by heat and cold. Fig. 337 shows the hot spots and the cold spots in one very small area of the skin. These sense organs differ in the extent to which they are sensitive. Some of them are so sensitive that they react when you merely touch a hair on your arm; others do not react until actual painful treatment is accorded them.

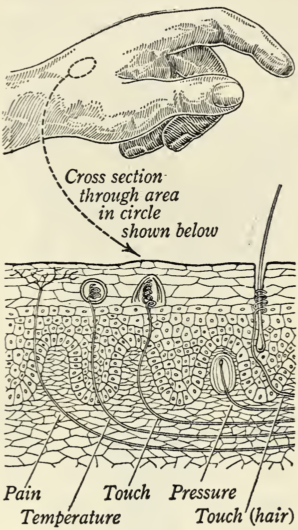


FIG. 337. The Tactile Receptors are Sensitive to Touch, Pain, Heat, and Cold

Countless numbers of these are distributed over the surface of the body

2. *The receptors for vision.* These, of course, are located in the eye and are sensitive to light. Let us look more closely at the eye and consider how it functions. Study Fig. 338. Notice the cornea, a layer of clear tissue through which the light waves first pass. They reach the lens of the eye, which acts very much like the lens of a camera, focusing the light rays as they pass. Notice, too, the iris, which functions like the shutter of a camera, reacting to the quantity of light. Thus if a very bright light strikes the eyes, the iris covers more of the lens, making a smaller opening. If the light is dull, the iris spreads apart, exposing a larger area of the lens upon which the light can fall. The light rays pass through the lens and focus upon the retina. Here are the receptors sensitive to light, a mass of rods and cones, as shown in Fig. 338, *C*, and more clearly in Fig. 338, *D*. The image is formed on these rods and cones. These are nerve endings of the optic nerve. We often say that the eye is the organ of sight.

The receptors for vision are located in the eye

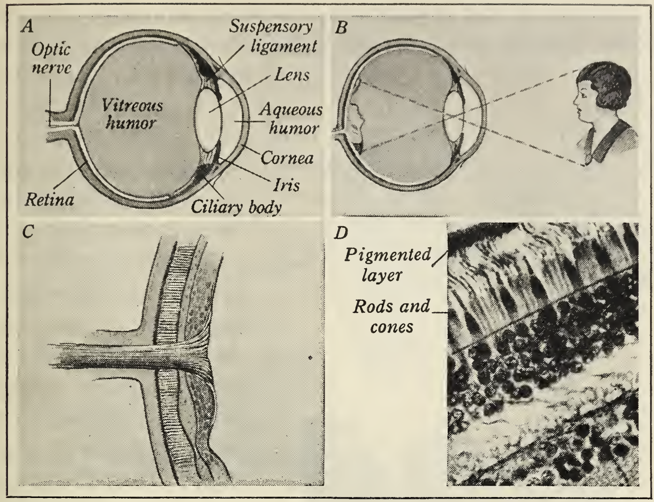


Fig. 338. The Receptors for Vision are located in the Eye

A, a diagram of the human eye; *B*, the image of an object is formed on the retina; *C*, a diagram of the retina (notice the rods and cones); *D*, a microphotograph of a section through the retina, showing the rods and cones

While this is true, strictly speaking the eye is only the organ which receives the stimulus of light. Sight as such is an interpretation of these stimuli, that is, the meaning given them by the individual. This interpretation is made in the brain and not in the eye. Any stimulation of the optic nerve is interpreted as sight. A severe bump on the head may stimulate the optic nerve and cause you to "see stars."

The eye is so constructed as to control the amount of light which may reach it

The eye is a very sensitive organ, and eye defects are not uncommon. Some of the most common ones may be explained through a simple experiment. Take a small hand lens such as a reading glass. Hold it before a piece of paper in such a way that rays of light fall upon the paper, forming the image of a near-by window. Now move the lens away from the paper. What happens? The image becomes blurred.

T

The lens of the eye acts in a manner similar to the lens of the reading glass in that it focuses the rays of light in such a way that they form an image upon the retina. Just how this happens you will learn later. The point to be understood now is that when the eye is structurally perfect, the lens of the eye focuses the rays of light in such a way that a perfect image is formed, as in Fig. 338, *B*. But the eye is not always structurally perfect, and so a perfect image may not be transmitted.

Fig. 339. Certain Structural Defects in the Eye may be corrected by Mechanical Means

In *a* you see the conditions existing in nearsightedness, and in *b* those in farsightedness. Notice how the lens of the eyeglass corrects the difficulty

Sometimes the lens is curved a little too much. The image then falls a little in front of the retina, as shown in Fig. 339, *a*. Such a condition is called nearsightedness. In other cases the lens may not be sufficiently curved, in which case the image will fall in back of the retina, as shown in Fig. 339, *b*. Then you have a condition called farsightedness. Still a third common defect is called astigmatism. The cause of this defect is a little more

complicated. The cornea, as well as the lens, serves as a focusing medium. An irregularity in the cornea may cause an image to form a little in front of the image formed by the lens. In other words, two images are formed, and this makes a blur. Astigmatism is a very common defect.

All these defects, however, may be remedied by carefully fitted eyeglasses, which, as you know, are really lenses so ground and curved that they offset, or balance, the irregularities of the eye and properly focus the rays of light on the retina. There are of course other defects. Some people, for example, are color-blind. One form of this defect is inability to distinguish red from green. The cause of this difficulty, however, is a very complex story.

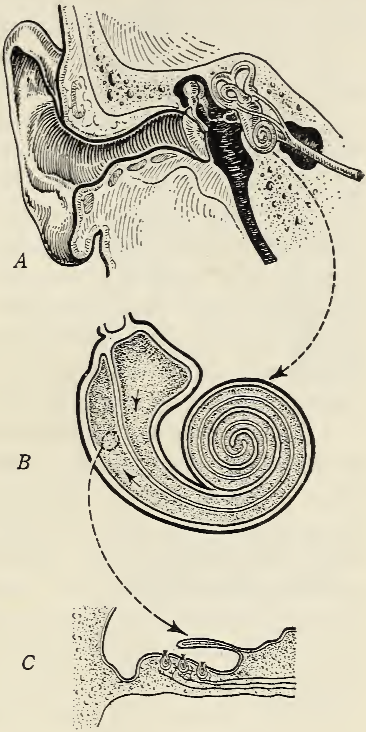


Fig. 340. The Receptors for Hearing are located in the Inner Ear

A, a cross section through the ear; *B*, the inner ear; *C*, the receptors for hearing

3. *The receptors for hearing.* These, of course, are found in the ear. You have already studied this organ and have seen how sound waves, entering the ear, pass through a canal and strike the eardrum. If you could look more closely at the inner ear, however, you would find a cavity containing liquid, as shown in Fig. 340, *B*. In this cavity, as shown, are certain cells sensitive to the stimuli produced by the sound

waves. If you could trace the nerves running from these sense organs, you would see them combine to form the large nerve called the auditory nerve. Like the optic nerve, it runs to the brain, and there the stimuli from the sound waves are interpreted as sound.

As with the eye, there are various defects which make it difficult for this organ properly to receive and interpret the sound waves. Some of these defects are comparatively simple and yield to local treatment. Young children sometimes have an irritated condition due to colds, which develops into a diseased condition of the mastoid process. This is a spongy bone which forms part of the middle ear. The Eustachian tube, which forms a connection between the middle ear and the back of the mouth, may also become inflamed as a result of colds. All these conditions may be remedied by expert medical attention.

Some defects of hearing are fairly easy to remedy; others are extremely difficult

A far more serious condition exists, however, when structural defects affect hearing. Sometimes the eardrum or the inner bones of the ear may be incompletely developed, or by accident they may be injured in such a manner as to affect the hearing. Such conditions require the most careful and scientific attention. Certain electrical instruments, which make the sound waves more intense and carry them to the ear with greater volume, may be helpful. Even such aids, however, should not be used without expert advice.

4. *The receptors for smell.* These, as shown in Fig. 341, are located in the nasal passages. Molecules of matter pass through the air into the nose. Here they dissolve, and stimulate the sense organs. These convey stimuli through a main nerve, called the olfactory (smelling) nerve, to the brain, where they are interpreted as odors of various kinds. This receptor is extremely sensitive, as is demonstrated by the fact that only a few drops of ammonia are sufficient to produce an odor throughout a schoolroom.

Molecules of a gas stimulate receptors for smell

5. *The receptors for taste.* Explore the surface of the tongue by using a drop of weak vinegar on the end of a clean glass rod or a toothpick. First touch the top of the tongue well toward the back of your mouth. Do you immediately taste the vinegar? Now wash out your mouth with water and try again. This time touch one side of the tongue. Does this experience tell you where the taste buds are located? If you could examine the surface of the tongue, you would find a great number of crevices containing the sense organs for taste, called taste buds. They are shown in Fig. 342. These organs are sensitive to four kinds of taste: bitter, salt, sweet, and sour. As substances reach the tongue, they pass around these taste buds. The buds react to the substance and convey the stimulus to the brain, to be interpreted as taste. Sometimes we say that a substance is tasteless. What we mean is that it does not possess any of the four qualities mentioned and therefore cannot be recognized by the taste buds on the tongue. Ordinarily we don't like a tasteless substance.

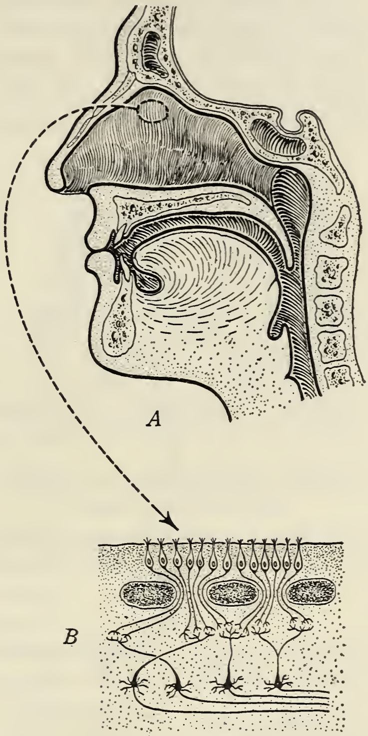


FIG. 341. The Receptors for Smell are located in the Nose

A, a cross section through the nose, showing the olfactory area; *B*, a small section of the area greatly magnified to show receptors for smell

Sulfur, for example, is tasteless; but if you have ever taken it for medicine, you probably thought it very bad. (Sulfur is really useless as a medicine.)

All these receptors are adapted to their special functions. Thus the receptors for smell are not sensitive to pain, although scattered among the special sense organs, such as those for smell, are also receptors sensitive to pain. You know, for example, that a sip of cocoa may taste sweet, but it may also be too hot. In such an instance two types of receptors are functioning. Perhaps you can think of similar instances, or even of situations in which several types function.

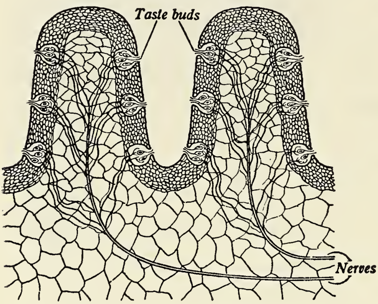


Fig. 342. The Receptors for Taste are located on the Tongue

A diagram of a part of the tongue, greatly enlarged. A crevice shows clearly the taste buds

Now let us look at the connecting organs. We have already said that each receptor, or sense organ, is attached to a nerve which carries the stimuli to a connecting organ. Fig. 343 shows such a nerve. Study it closely. Notice that the nerve includes a cell body which has branching out from it certain fibers, somewhat like the branches of a tree. This complete connecting mechanism is called a neuron; and since in this case it conveys an impulse *from* a sense organ, it is called a sensory neuron. Imagine now that the sense organ has been stimulated in some manner. An impulse travels along the neuron, coming to the cell body. It excites other fibers which may be near and which are a part of another nerve cell. What happens now?

Nerve fibers, called sensory neurons, carry stimuli from the sense organs to the central nervous system

Before we answer this question, we must look at another part of the connecting organs, the central nervous system. It is divided into three sections. One part consists of the brain itself; another of the mid-brain, located at the base of the skull; and the third of the spinal cord, which is inclosed in the backbone. Consider this central nervous system as a mass of neurons which may receive impulses from the sensory neurons and send impulses to the reacting organs.

The central nervous system receives impulses from the sense organs

Let us now go back to the impulse which had reached the cell body of the sensory neuron. Remember that in the central nervous system are other neurons, called central neurons, whose particular function it is to receive impulses from the sensory neurons. These too have a cell body and a surrounding group of fibers. The impulse carried in the sensory neuron is transferred to the central neuron across the gap (called the synapse), where the fibers of the sensory neuron are very close to the fibers of the central neuron. The fibers of the two may really touch, or they may not. No one is certain as to just how the transfer is made. In some cases the impulses cannot be transferred, and nothing happens. Let us imagine that the impulse has been transferred and has reached the central neuron in the central nervous system. What happens now? This depends upon many factors. We must consider

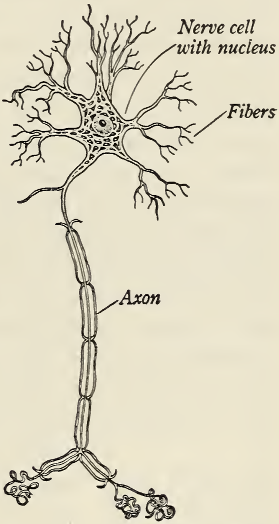


Fig. 343. Nerve Fibers, called Sensory Neurons, carry Stimuli from the Sense Organs to the Central Nervous System

This diagram shows one of the millions of neurons, greatly enlarged, which form a part of the human nervous system

among other things the source of the impulse and the conditions which gave rise to it.

Imagine a rainy afternoon. You are sitting in your bedroom reading a really exciting story. Suddenly you hear your mother call from the next room, asking you to go into the kitchen and take the teapot off the stove. You get up and start for the kitchen, wondering what is going to happen to the hero in the story, who has just been attacked by a band of wild Indians. Your thought only partly on the job you are to do, you walk into the kitchen and absent-mindedly reach for the earthen teapot. You have not even thought of the possibility that the teapot may be hot, but you soon discover that it is. You pick it up, but suddenly let it drop to the stove, where it is broken. You did not mean to drop the pot, but the action was instinctive, or automatic. You did not even think about it. How may the action be explained? In this particular instance a sense organ in your hand received the stimulus from the hot teapot. The impulse was immediately transferred by a sensory neuron to the central nervous system, and here the connecting organs automatically transferred it to the proper reacting organs, in this case certain muscles, which caused you to open your hand and pull it away. Here was a very simple connection from a sense organ to a sensory neuron, to the central nervous system, to a motor neuron, to your muscles. The connections are shown in Fig. 344, *a*. Notice that in describing this type of response we use the word *instinctive*. Such an action is known as a reflex action and is called a reaction on the first level. It is very common. You pull your hand away from a sharp object, you stop at the sound of an automobile horn, or you turn your eyes away from a bright light. Notice from Fig. 344, *a*, that the action here takes place between the receptor and the spinal cord and that it does not make use of the brain as we commonly refer to it.

The stimuli received by the sense organs may result in reactions ranging from very simple to very complex

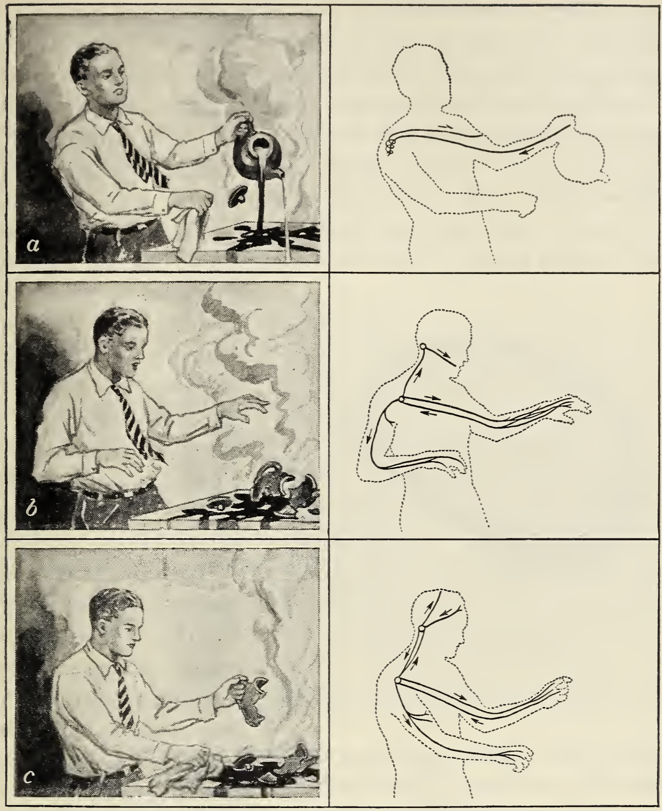


FIG. 344. The Stimuli received by Sense Organs may result in Reactions ranging from Very Simple to Very Complex

As you read the story of the broken teapot, study these pictures

In addition to opening your hand and dropping the teapot, however, you probably wrinkled your face in pain or shook your hand. Was the action in directing these other motions as simple as those that caused you to jerk away your hand? Look at Fig. 344, *b*. Notice the same reflex action as before, but notice that another path is shown

leading up to the mid-brain and from there out into other muscles. The action here is slightly more complex. Such reactions are said to be on the second, or mid-brain, level.

Responses are on different levels

Now let us go still farther. As the teapot crashes, you forget all about the hero of your story. You consider the broken teapot and decide that you had better get rid of the pieces. Remembering your burn, however, you find an asbestos pot-holder and pick up the pieces of the teapot carefully, placing them in the trash barrel. Now another step has been added to the nervous reaction, as you can see from Fig. 344, *c*. Several areas are at work, including the highly specialized area of the brain.

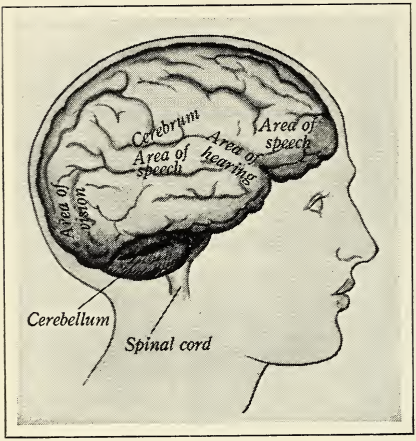


Fig. 345. The Brain is made up of Several Parts, all containing a Large Number of Nerve Cells

The cerebrum of other animals is not so highly developed as is that of man

We said at the beginning of this chapter that the cerebrospinal system controls voluntary action. Do you see this from the illustrations we have given above?

Should you say that any one part of the cerebrospinal nervous system is more important than any other? While this is a difficult question to answer, one thing is obvious: in man the high development of the brain is a distinguishing feature. If you will refer again to Fig. 344, you will find that all the reactions which demand what we usually consider "thought" seem to have their origin in the brain. What is this organ?

While we usually think of the brain as one organ, you will see from Fig. 345 that there are really several parts. Not all of them need be considered. The one with which we are directly concerned now is called the cerebrum (the Latin word for "brain"). This in man is far more highly developed than in other animals, and in this respect indicates the growth of man toward intelligence. The outer part of the cerebrum is called the cortex. The cortex, a mass of gray matter, is folded, giving the familiar appearance shown in pictures of the brain.

As you will recall, the different nerves run from the organs to the brain. Scientists believe that nerves leading from one receptor end in a certain area of the cortex. For example, one area forms the center of sight, another the center of hearing. There are certain observations which support this belief. As a result of accidents to certain areas of the cortex, individuals have been made blind or deaf while the external organ of sight or of hearing remained perfectly normal. Experiments have shown that animals may be deprived of certain senses by destroying certain sections of the cortex.

B. What is the Autonomic Nervous System?

You have already seen how certain organs within the body perform their work without any conscious action on the part of the individual. Among these organs are the intestines, the spleen, the liver, the heart, and the kidneys. All these are under the control of the autonomic nervous system.

Study Fig. 346 carefully. Notice that the centers of the autonomic nervous system are not located in the spinal cord but seem to gather in centers paralleling the spinal cord. These centers are called ganglia. From these ganglia, as you can see, nerves run to various organs of the body. The arrangement and working of these nerves are similar to those of the cerebrospinal system.

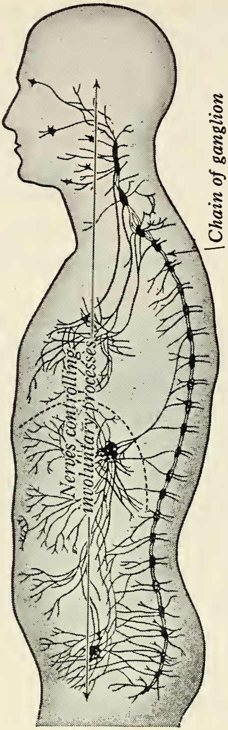


Fig. 346. The Centers of the Autonomic Nervous System are in a Chain of Ganglia lying just in front of the Spinal Cord

This system, which is responsible for most of our involuntary action, is a part of the complete nervous system since, as you can see from this diagram, it is connected to the spinal cord and the brain

The importance of the autonomic nervous system lies in several factors. First, study the organs which it serves. Second, consider the fact that the action of this system is automatic to a great extent. In other words, it controls automatically many of the important life processes. As one scientist has stated it, the autonomic system "by taking over most of the routine drudgery of living . . . releases the central nervous system for higher evolutionary adventures."

The autonomic nervous system must not be thought of as one separate from the cerebrospinal system. Rather it is a part of the whole system which controls the body. There are connections from the autonomic ganglia to the spinal column and thus to the brain. Therefore it is possible for the brain under certain conditions to maintain control over these bodily organs. The interesting point, however, is that these two systems are opposed to each other in the effect they have upon certain organs. Thus if a stimulus acts on the spinal nerve controlling the salivary gland, saliva flows. If a stimulus acts on the autonomic nerve controlling this same gland, the flow of saliva is stopped. The relationship between

these two systems might be stated by saying that they balance each other. Do you see why? You have seen how the body is controlled during violent exercise. Breathing increases as the cells demand oxygen. At the same time the heartbeat increases also, and so on. All this is controlled by the autonomic system.

The autonomic nervous system is responsible for most involuntary action

Emotional responses, such as those associated with pain, fear, and anger, seem to be related to the autonomic system. There is a connection between the cerebrospinal and autonomic systems. It seems as if strong stimulation of the cerebrospinal system runs over into the autonomic. Severe pain affects the flow of saliva and of gastric juice. Fear makes the heart beat faster. There are many other illustrations which show that stimulation of the cerebrospinal system affects processes governed by the autonomic system.

C. How is Man Unlike Other Animals?

What is thought? What happens as you think your way out of difficulty? No one really knows, although many theories have been advanced. All that we can be certain of is that thought comes as the result of certain connections through the nervous system. Many factors, such as habit and memory, play a part in it.

It is believed, for example, that when a certain stimulus with its natural response is practiced many times the nervous mechanism becomes trained to it and responds more quickly when the same stimulus is applied. Perhaps you hated to drill on arithmetic combinations. Yet you know that this drill helped you to give more and more rapidly the correct answers to your problems. Why was this? According to one theory the stimulus-response connection to a certain combination had, through long practice and drill, become automatic. Perhaps you know how difficult it is for

people to change certain habits which they have acquired. Why should this be so? One theory holds that constant repetition of certain reactions has set up many automatic habits, channels or grooves, so to speak, and that the individual's responses seem to follow these grooves.

Here you have the chief difference between man and other animals. Man possesses a conscious power which enables him to make adjustments for himself, to reason about his environment, and to use his experiences — in short, to think! It is this ability that enables him to control living things and use them to suit his purposes. It is the same ability that enables him to control the forces and use the materials of the physical environment to meet his demands for physical comforts.

The nervous system controls man's reactions to stimuli in his environment. One main division of this system, the cerebrospinal, controls voluntary and reflex action, while the other, the autonomic, directs most of involuntary action. The more complex reactions, requiring thought processes, distinguish man from other animals.

Can You Answer these Questions?

1. What part does the cerebrospinal nervous system play in the functioning of the body?

2. What are the sensory organs, where are they located, and what are the characteristics of each?

3. What are the steps by which light is interpreted as sight?

4. What are the causes of nearsightedness, farsightedness, and astigmatism? How may these conditions be corrected?

5. How are the stimuli received by the sensory organs transferred to the central nervous system?

6. What is meant by nervous reactions on the first, second, and third levels?

7. What is the function of the autonomic nervous system? Why is it important in the functioning of the body?

8. In terms of the nervous system what is one explanation of the statement "Practice makes perfect"?

Questions for Discussion

1. How would you explain the thinking process?

2. Do you believe that a dog or a horse can think? How might you explain some of the clever things they do?

3. We often speak of doing something by instinct. What do you think this really means?

4. Consider some common, everyday incidents. You see a fancy pencil in a store window and buy it. Can you trace some of the nervous reactions which take place during this process?

5. What evidence would you present in support of the statement that man is more intelligent than other animals? Can you think of any instances that would support an opposite point of view?

6. Some scientists advance the theory that nervous reactions are really electrical in nature. Does this seem reasonable to you?

7. What advantages can you see in the fact that the autonomic and cerebrospinal nervous systems are opposed to each other in the effect they have upon certain organs?

Here are Some Things You May Want to Do

1. See if you can find some simple mechanical puzzles entirely new to you, such as a pair of bent nails which may be taken apart, or a pair of rings which are linked together. There are many others. Time yourself in solving these on successive attempts. Can you do all of them in less and less time? What does a graph of your results look like?

2. Make a list of common reactions on the various levels. After each one, explain why you classified it as you did.

3. Try to prepare a simple scientific talk on the topic "Why it is important that proper work, study, and behavior habits be established early in life."

Chapter XXVI · What are the Causes of Illness, and How may we avoid Them?

Among all the human desires the one for health has always occupied a prominent place. We find references to it throughout all recorded history and can safely guess that this desire was equally strong among prehistoric people.

While the desire for good health has always been present, the means for controlling the causes of ill health is a recent achievement. We like to think of our modern civilization as one in which principles of sanitation are effectively applied. We often hear a community referred to as sanitary, meaning that effective measures are being taken to control the causes of ill health. You may compare communities by referring to tables of figures showing illness and death rates. If you have a health officer in your community, he will probably be glad to come to your school and talk to you about community sanitation.

Man has made great progress in his efforts to control ill health

During recent years man has been able to accomplish much in reducing illness and in finding ways by which disease formerly thought incurable can be prevented and cured. In the earliest historical records there are accounts of methods used to cure the sick. Some of the methods seem strange indeed to us today. Some command our very great respect. All bear abundant testimony to the eagerness of man to keep well. Let us look back into history and see some of the things man has done in his fight against diseases. In this way we may perhaps gain a better idea of how far we have progressed.

The ancient Babylonians, who lived long before the birth of Christ, brought their sick to the market place, where they told their troubles to those who passed by. People who had suffered similar ailments told how they

had been cured, and the sick person chose from what he was told the treatment he wished to take. Perhaps this does not seem so ancient, after all. The conversation in the ancient Babylonian market place must have been similar to that of the market place today, for people still like to tell of their ailments and what they did to cure themselves.

Man's fight against ill health is as old as the race

With the Babylonians, however, as with other ancient people, cures were sought through belief in charms, religious ceremony, and the use of drugs. Remedies to be taken internally included herbs, honey, and many others. These people also practiced bloodletting, a process in which blood was taken from the body. They probably worked on the supposition that "bad blood" should be drawn from the body to free the patient of his illness. The Babylonians also used hot and cold baths in their treatments, as well as salves and oil to massage, or rub, the parts of the body in which pain was felt.

Among the early Greeks the name of Æsculapius is associated with the treatment of disease. According to Greek myths he was the son of Apollo, god of manly youth and beauty, of poetry and music, and of healing. It is interesting to notice that the god of medicine was the son of the god with whom the noblest powers were associated. Should you say that Æsculapius, as pictured in Fig. 347, is a fitting god of health? According to Greek myths Æsculapius was educated by a centaur named Chiron, half man and half horse. He was taught the healing power of herbs and was said to have gained such powers in the treatment of disease that he was able to bring the dead to life. He became so powerful that he offended Zeus, the god of wind, rain, lightning, and of moral law. For this offense Zeus killed Æsculapius with a flash of lightning.

Some ancient health practices were based upon superstition and magic

Temples similar to the one in Fig. 348 were erected to this god of medicine, and they served as places of worship

and as places for treatment of the sick. The patient was received at the temple by a priest, and certain ceremonies were performed, including the sacrifice of a rooster or a ram. The sufferer would then sleep in the temple. According to the belief, if he were earnest and reverent, Æsculapius would appear to him in a dream and tell him what to do to become well. The priest of the temple then interpreted the dream and directed the treatment. Strange to say, this was of the kind commonly recognized today as best for most ailments. It included good foods, physical exercise, massage, bathing, sunshine, and fresh air. Some drugs were known, and these were used when the condition of the patient seemed to require them.

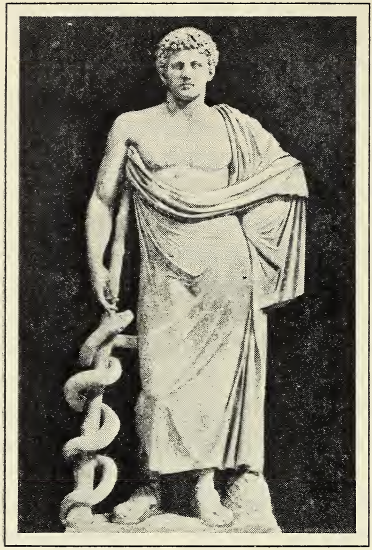


Fig. 347. Æsculapius was a Greek God of Medicine

Do you know of any other ancient health gods?

Those who recovered left as an offering to the god a tablet of stone giving the history and treatment of the disease. These tablets were prominently displayed in the temple. Perhaps the Greeks followed the methods of modern advertising, for no records were kept of those who failed to obtain a cure! It is easy to imagine the effects that might come from the display of these tablets. The incoming patients saw the accounts of marvelous cures. Belief in these cures would certainly have a wholesome in-

Some ancient health practices seem fairly effective

Fig. 348. Not so very long ago Temples such as this were erected to Gods of Health and Medicine

Many such temples were built in Greece and Rome. These ancient temples must have served as fairly good hospitals

fluence upon the new patients. Together with good food, sunshine, fresh air, and other means employed in treatment, such belief must have helped to make these ancient temples fairly effective hospitals. These temples were prominent in the history of Greece and neighboring countries for more than a thousand years.

The American Indians used strange religious ceremonies in the treatment of their sick. These ceremonies were typical of those followed by other primitive people. The priest-physician, dressed in a costume similar to that shown in Fig. 349, used strange equipment, including rattles, feathers, eagle claws, the foot of some animal, together with other things. With this equipment he would endeavor to drive out the evil spirit of any illness. The religious ceremony was strengthened by other treatments, including the use of herbs. Sweat baths were also used by the Indians as a favorite method of treatment.

From this brief account you can see that health has always been a matter of interest to people and that all of them have attempted in one way or another to overcome the difficulties which have affected health. Let us now come down to the present day.

Field Museum of Natural History

Fig. 349. The Health Practices of the American Indian were sometimes based upon Superstition and Magic

What other purposes than that of a healer did the medicine man serve?

A. What causes Illness?

Let us at the very beginning give you an answer to this question and then see if we can give you a sufficient number of illustrations to make the answer clear. Let us say that illness is caused by a condition in the body which disturbs the normal functioning of the body. A condition of health is a condition of normal functioning. A condition of illness is one in which normal functioning fails.

You have already seen how the normal working of the body depends upon a beautiful balance between the various organs of the body. You have seen, for example, how food passes through the walls of certain organs of digestion, into the blood, and is distributed to the cells as needed for growth and for energy. Can this balanced functioning be

disturbed? Waste products from the release of energy enter the blood from the cells. They are carried to the lungs and to the kidneys. Through these organs the wastes are separated from the blood and conveyed outside the body. Are there possibilities of disturbance to the balanced functioning of these processes? Consider impure air or improper habits of getting rid of waste. Think, too, if you will, of the complex nervous system which you have seen, and think of the many chances that normal functioning may be disturbed here. Do these familiar explanations make our answer to the question at the beginning of this section any clearer?

A body functioning normally is a body in which balance is maintained

There are, of course, many other causes of disturbance than those we have illustrated. In general the explanation for disturbed functioning may be found in one or more of six types of disorders. These are disorders due to incorrect diet, bacterial infection, poisons, faulty gland action, structural defects, and accidents.

Ill health is caused by a disturbance in the normal balance between the various organs of the body

You are already familiar with some of these disorders. You know something of the functions served by proteins, carbohydrates, and fats. You have seen evidence of the importance of vitamins in the diet. Disturbed functioning due to poisoning is not new to you, for in your previous work in science you have studied the effects of alcohol, tobacco, and some of the poisonous gases upon the human organism. You have also seen in the last few chapters how some structural defects often cause difficulty. As you consider the parts of the body, it seems extremely complex. There is the blood with its many ingredients and always changing. There are organs of digestion and digestive juices, there are glands of internal secretion, and other parts. In health all these work together. Let us look now at some of the causes of unbalanced functioning.

B. What Part does the Blood play in Normal Functioning?

The blood is a complex substance

If you could examine the blood of a healthy person, you would find it a complex substance, forming about 9 per cent of the total weight of the body. The liquid part of the blood is called plasma, and floating in the plasma are the red and white cells. About two thirds of the weight of the blood is plasma. The cells make up one third. Let us examine the liquid part, the plasma. This is about 90 per cent water and 10 per cent solids. If you recall how foods are transported through the system, you may perhaps guess that these solids are dissolved food substances. So they are, in great part. In addition to the foods there are mineral salts.

It is interesting to notice how the various substances composing the plasma are kept in a nice balance. There is, for example, about 0.1 per cent of sugar in the normal sample of plasma. This may range as low as 0.07 per cent under conditions of health or as high as 0.18 per cent. If the concentration runs higher than 0.18 per cent, as it may following a heavy feast of candy, the surplus is carried off through the kidneys as waste. Only in illness does the percentage run lower than 0.07 per cent. Thus the body through normal functioning regulates the amount of sugar in the blood. Other substances in the blood, too, are regulated. The concentration of salts is maintained at about 0.6 per cent, with a normal change of not more than 0.1 per cent below or above that amount.

Other substances are found in the plasma, but they are present in very small amounts. There is a substance which causes the plasma to clot, or thicken, when it comes in contact with injured tissue. If you have ever had your tonsils taken out or perhaps had some other kind of operation, you know that one of the tests given you was one to see whether or not your blood clotted properly. You can see the im-

portance of this. Certain people are called "bleeders," or, in scientific terms, they are said to suffer from hæmophilia. This disease is hereditary and is passed on from generation to generation.

As a part of the plasma, too, there are substances which destroy the effects of poisons which may get into the body. You may study these a little later. There are also regulating substances which come from the glands of internal secretion. These are important. In Fig. 350 is indicated the location of some of these glands in the body. Their effects upon the organism have been carefully studied, but much remains to be learned about them. The thyroid gland, located in the neck, produces a secretion which plays a most important part in regulation of the manner in which the body uses food. A secretion from the parathyroids regulates the use of calcium, which, as you know, is a very important element in the growth of bones. The pituitary body at the base of the brain furnishes a secretion which regulates the rate of growth in bones. A secretion called insulin, taken up by the blood as it flows through the pancreas, regulates the use of sugar. The balance of sugar in the blood cannot be maintained without this secretion.

Secretions of the glands play an important part in bodily processes

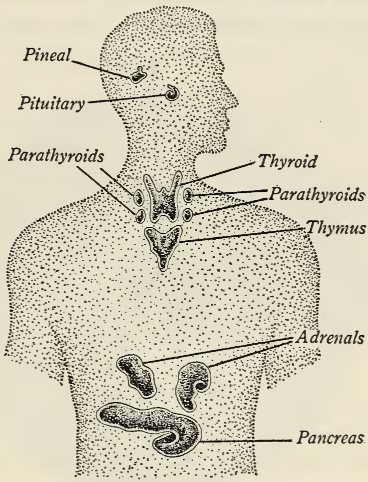


FIG. 350. Secretions of the Various Glands play an Important Part in Bodily Processes

Defects of the glands may result in serious defects in the functioning of the human organism

There are other glands of internal secretion. Each pours into the blood a particular regulating substance. These internal secretions are called hormones, a word meaning to "excite" or "cause to act." Since the hormones are essential in the maintenance of the balance within the body, it is easy to understand that failure of these glands to function properly will cause illness.

Red corpuscles carry oxygen to the cells

Now let us look at another important part of the blood. If you could look at a sample of blood under a powerful microscope, you would see, as in Fig. 351, that it contains many small particles. Most of them are red in color, but some are white. You already know something of the function of the red corpuscles. They combine with oxygen as they flow with the blood through the lungs, and they release oxygen to the cells for the oxidation of food. The combining takes place where there is a surplus of oxygen; the release takes place where there is a shortage of oxygen. As you can judge from Fig. 351, these corpuscles are extremely tiny. In man there are normally 5,000,000 in 1 cubic millimeter. Perhaps we can make this mean more. The little cube shown in Fig. 352 represents 1 cubic centimeter. This, as you may know, is 1000 cubic millimeters. The blood required to

Fig. 351. About One Third of the Total Weight of the Blood is made up of Red and White Corpuscles

This photograph of a very small portion of blood was taken through a microscope

fill this small volume of 1 cubic centimeter will contain 5,000,000,000 red corpuscles. In women the number of red corpuscles per unit volume is a little less than in men, about 4,500,000,000 in 1 cubic centimeter.

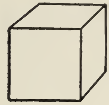


FIG. 352. A Cubic Centimeter of Blood contains from Four and a Half to Five Billion Red Corpuscles

In the normal work of the body red corpuscles are destroyed and new ones are supplied. You learned in your study of bones that the source of supply for new ones is the bone marrow. As the result of certain diseases the number of red corpuscles may be considerably reduced. A person suffering from a definite shortage of red corpuscles is said to have anæmia. It is obvious that a condition of anæmia will interfere seriously with normal functioning of the body.

How about the white corpuscles? An important function of these corpuscles is to keep the blood free from invading organisms, especially bacteria, plants so small that they can be seen only through a microscope. The white corpuscles devour and digest the living organisms that get into the blood. Study Fig. 353. Normally there are from 5000 to 15,000 white corpuscles in each cubic millimeter of blood, or, roughly, 1 white to 1000 red ones. In case of disease the number may be very much greater. In an injury, as when you cut your finger, white corpuscles collect in the tissue near it and act as guards against bacteria. The pus which forms about an infected cut contains many white corpuscles. These white corpuscles seem always to increase in number when more are needed. An increase in their number is evidence of internal infection.

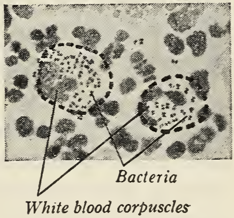


FIG. 353. The White Corpuscles of the Blood aid in fighting Bacterial Diseases

This photograph, showing white corpuscles destroying and digesting living organisms, was taken through a microscope

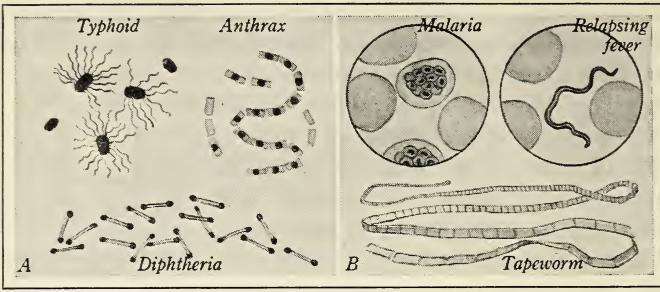


FIG. 354. Two Kinds of Parasites, Plant and Animal, may live within the Body and cause Disease

Some common parasites of both types are shown above

C. How do Microörganisms affect the Health of the Body?

Two kinds of parasites, plant and animal, may live within the body and cause disease. Some are shown in Fig. 354. The tiny plant parasites associated with many diseases are known as bacteria. There are many kinds, but only a few produce any harmful effect upon the human body. Of the animal parasites there are the Protozoa, which are tiny single-celled animals; and there are larger parasites, such as the hookworm, tapeworm, and others. The same organisms, however, always produce the same disease. Let us look at some of them.

Plant and animal parasites cause disease

You know something of the causes of malaria. It is caused by a tiny protozoan and is carried from one person to another by mosquitoes. But the tiny parasites have a peculiar life cycle, for part of it must be spent in the body of a mosquito, and part in the body of a human being. Because of this fact the parasite may not pass directly from one person to another nor from one mosquito to another. It can pass from man to man only by way of a mosquito, and from mosquito

Malaria is caused by a protozoan

A malarial patient is bitten by an *Anopheles* mosquito

Malaria parasites are carried in the body of the mosquito

The malaria parasites may be transmitted to a healthy person

Fig. 355. Part of the Life Cycle of the Malaria Parasite is spent in the Body of the Mosquito, and Part in the Body of a Human Being

to mosquito only by way of a human being, as shown in Fig. 355. In the blood stream the parasite attacks and feeds upon the red corpuscles. The destruction of red corpuscles and the presence of waste products produced from this destruction cause the symptoms of the disease. Thus anæmia is a normal accompaniment of malaria. It should be easy to see how malaria may disturb the normal functioning of the body. The control of malaria, of course, depends upon destroying the mosquito carrying the parasite. You have read in your previous science work how this is done. This control may be very effective. In some communities in which malaria was once a common illness it is now almost unknown.

One of the most interesting stories in the history of man's control over bacterial diseases is found in his attempts to fight tropical diseases. Under conditions of heat and moisture it is difficult indeed to apply measures for sanitation. But let us illustrate by telling some of the things that have been done.

At the time of the Spanish-American War our soldiers in Cuba suffered a great deal from yellow fever. No one knew how the disease was carried. It was believed that it was contagious; that is, that one person could give the disease to another by mere contact. Directly after the war, army physicians began working on the problem. With the aid of volunteers, some of whom died in the

Yellow fever is carried from one person to another by a mosquito

experiment, it was found that yellow fever, like malaria, is carried by a mosquito. The yellow-fever mosquito is called *Aëdes egypti.* To prove the cause of this illness, one of these mosquitoes was allowed to suck blood from a person suffering from it. A little later this mosquito was allowed to bite a healthy person. This healthy person was a private soldier who had volunteered for the test. The soldier contracted the disease. These observations, along with many others, were taken as proof of the manner in which this disease is spread. As a result of these observations a drive was made to clean up the breeding places of the mosquito. Today yellow fever is practically unknown in the United States, and such former centers of the disease as Cuba (see Fig. 356) and the Canal Zone are comparatively free from it. In the case of malaria the parasite causing the disease has been discovered. In the case of yellow fever it has not; so the real cause of yellow fever remains unknown.

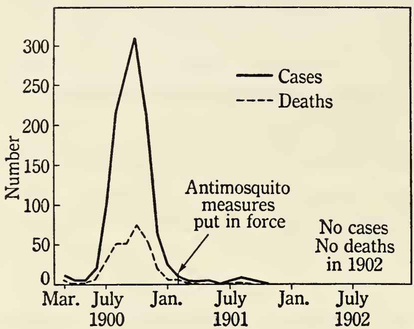


Fig. 356. By Applying Scientific Knowledge, Yellow Fever has been almost completely wiped out in Many Parts of the World

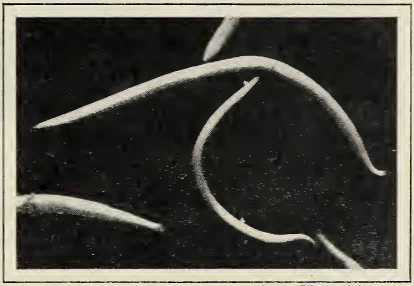
The graph shows control of the disease in Havana.[1] What do you think caused the drop?

The course by which some organisms enter the body seems almost too strange to be true. Consider the hookworm, for example. This organism (Fig. 357) may live as a parasite in the intestine of man. It attaches itself to the walls of the intestine, and its action results in the loss of considerable blood. Sufferers are anæmic and consequently

[1] From *Public Health in the United States,* by Harry H. Moore, published by Harper & Brothers.

very low in physical endurance. Hookworms pass, in the waste material, from the body of an infected person. Under favorable conditions they may live for some time in the soil where deposited. Hookworm disease is common in warm regions where people go barefooted. The parasite commonly enters the body of a victim through the skin between the toes. Once in the blood, hookworms may be carried in the circulation to the lungs. Here they penetrate the air pouches, or sacs, and enter the breathing passage. They may be coughed up from the lungs, swallowed, and finally reach their lodging place in the intestine. Hookworm disease may be cured by proper treatment with drugs. It may be prevented by application of proper sanitation. It is a filth disease and develops under conditions like those shown in Fig. 358. It cannot develop if sewage is properly disposed of.

The hookworm parasite lives in the intestine



Army Medical Museum

Fig. 357. The Hookworm Parasite lives in the Intestine

These parasites are much magnified

There are other animal parasites that cause disease. Most known parasites, however, may be controlled. In order that there may be control, it is necessary to know the life history of the organism. Do you see why this knowledge is necessary?

Among the diseases known to be caused by bacteria are diphtheria, typhoid fever, tuberculosis, tetanus, and plague.

Diphtheria, a highly contagious disease, is caused by bacteria that may live in the throat. It is easy to understand how this illness is spread. A sufferer from the disease

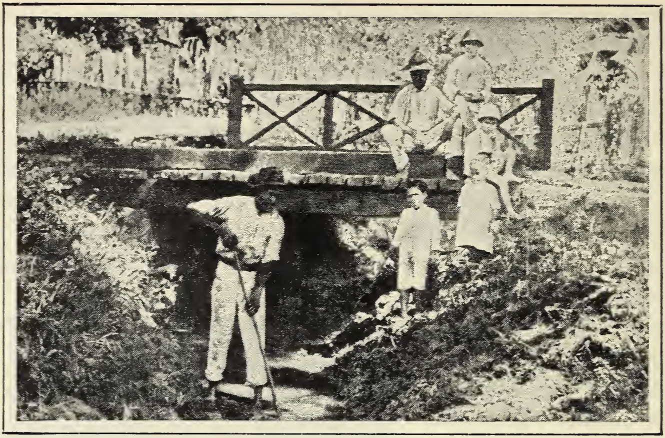


FIG. 358. Why should Conditions such as these be Favorable for Hookworm?

Notice the bare feet and the sewage-infected stream. How may the conditions be remedied?

may hurl little droplets of moisture from the throat by coughing or by talking. Bacteria may be carried in these droplets into the air, and into the throat of another person as he breathes. Fortunately these bacteria will remain alive in air for only a short time; so one can hardly catch the disease unless he is very close to the person who has it. As the organism lives in the throat, it feeds upon the mucus secreted there. Waste products are formed, and among them is a substance called toxin (a word meaning "poison"). This poisonous substance passes into the blood and causes the symptoms of the disease.

The bacteria of diphtheria produce a toxin in the blood stream

You have already learned that one function of the blood is to resist the effects of poisons. It seems that all of us have within our blood a special substance for resisting the effects of diphtheria toxin. We may call this substance the antitoxin of diphtheria. Every person seems to have some power of resistance against this disease. As the bac-

teria grow in the throat and release toxin into the blood, the body normally reacts against the invasion, and the patient may recover from the disease without aid. Some people seem to be entirely immune to the disease; others may have it in such a light form that they are hardly conscious of any illness at all. All too often, however, the disease results in painful suffering and death. It had been observed many times that most of those who have diphtheria do not have it a second time. One illness makes them immune. In the search for a treatment for the disease a method was sought that would produce in the blood, without having the disease, the same effects as are produced by having it.

The human body produces antitoxin in small amounts

The treatment of diphtheria is one which gives aid to the natural resistance. There is some antitoxin normally in the blood. As the disease advances, the concentration of antitoxin increases. But it may not increase fast enough. As an added protection the physician injects (inserts) doses of antitoxin into the blood. If the disease is recognized early and antitoxin is immediately injected, the danger of death or severe consequences from diphtheria is very slight.

Where does the physician obtain antitoxin for diphtheria? In general the answer is simple. The bacteria of diphtheria may be grown in a test tube, and in this condition toxin is produced just as in the throat. The toxin is dissolved in liquid. The bacteria are tiny, but with a very fine filter the liquid containing the toxin may be filtered from the tiny organisms. Now suppose some of this liquid is injected into an animal, say a horse. Will the horse have diphtheria? Of course it cannot; for there are no bacteria in the toxin, and only the bacteria can cause the disease. The horse may, however, suffer somewhat from the effects of the poisonous toxin.

The blood of the horse resists the effects of the toxin by developing an antitoxin. In practice a small dose of toxin

separated from bacteria that grew in a test tube is injected into the blood stream of a horse. Some antitoxin forms in the blood of the horse to resist its effects. In a few days a second dose, larger than the first, is injected. More antitoxin is produced. The treatment is continued with increasing doses until the horse is able to take and resist a very large amount of toxin. Now the horse's blood contains a large amount of antitoxin. Since the horse is a large animal, a considerable quantity of blood may be drawn from its body without noticeable injury. Antitoxin may be separated from this blood and used to save the lives of children after they have contracted diphtheria. Some steps in the production of antitoxin are shown in Fig. 359.

Antitoxin is produced commercially and used to help the human organism

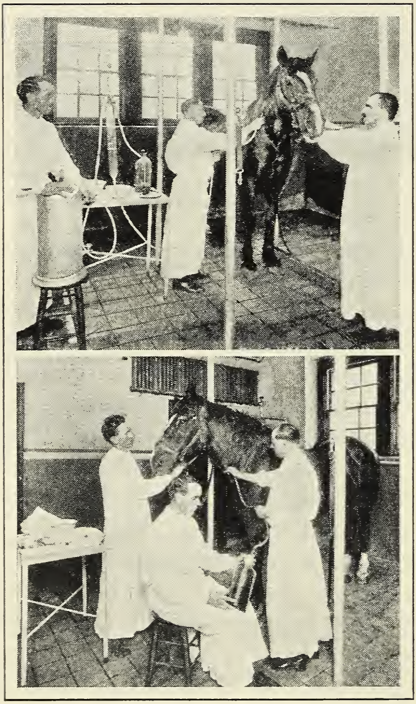


Fig. 359. Some Kinds of Antitoxin are produced commercially and used to help the Human Organism

Antitoxin for diphtheria is produced in the blood of healthy horses. The toxin may be produced by bacteria growing in a test tube

A few years ago a treatment known as the toxin-antitoxin was discovered for developing immunity against the disease. A person who is immune cannot catch it. The method is one which starts the development of antitoxin in a

person instead of in a horse. A mixture of toxin and antitoxin is injected into the body; the antitoxin balances the effects of the toxin, and the toxin induces the production of more antitoxin. When this is produced in the blood, the person acquires a protection similar to that produced by having the disease. Antitoxin for diphtheria was developed about 1890. The reduction in deaths from diphtheria since 1900 is shown in Fig. 360. No doubt the use of antitoxin has contributed a large part to this decrease. No doubt many successful men and women are alive and working today who would have died in childhood had not antitoxin been discovered. The control of diphtheria is one of man's great achievements. If the toxin-antitoxin treatment were given to all children, this disease could be completely wiped out.

Treatment in bacterial diseases is based on attempts to increase the normal resistance of the body

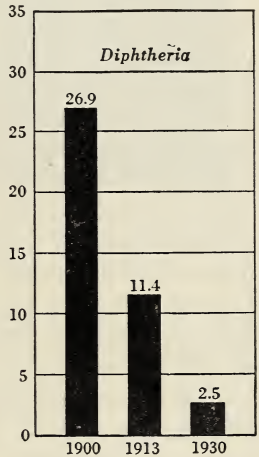


FIG. 360. The Discovery of Antitoxin for Diphtheria has caused a Tremendous Drop in the Death Rate from that Disease

The graph[1] shows the death rate per 100,000 population in New York State. Are you immune to this disease?

Other antitoxins have been developed by application of principles similar to those that have guided us in the production of antitoxin for diphtheria. There are effective antitoxins for tetanus, hydrophobia, and snake bite. Each of these is extremely dangerous if the antitoxin is not used, but there is almost no danger of death from any of them if the antitoxins are properly used.

The treatment of bacterial disease is based upon the supposition that the normal ability of the blood to resist

[1] From *Public Health in New York State*, published by Harper & Brothers.

invading bacteria may be strengthened. To develop immunity against typhoid, dead bacteria are injected beneath the skin. They act similarly to the toxin of diphtheria and produce, without causing the disease, a protection similar to that produced by having it.

Vaccination against smallpox causes a mild case of the disease. However, it is not harmful, and it develops an immunity which is protection against further attack from this disease.

The cause for some diseases is unknown

Not all diseases have been conquered. In some cases the cause of the infection is not yet known. In others it is, but man has not been able to find the proper means of fighting it. Thus while man has found the bacteria responsible for tuberculosis, he has not been able to develop an antitoxin which will control them. Many people believe it may be cured by drugs, however, and spend millions of dollars a year on treatments which are nothing but cruel fakes. So far the only help in tuberculosis has been found through rest, fresh air, sunshine, and good food. This treatment is effective; and if the "rest cure" is begun before the disease has run too far, recovery is usually complete.

Even some apparently simple causes of illness are yet a mystery to science. Consider the "common cold." We know it is contagious, but no one has found the bacterium responsible. Shall we ever find it? As we look upon the record of man in gradually increasing his control over other diseases, such as malaria, typhoid, scarlet fever, diphtheria, and yellow fever, it seems safe to predict that some day the mysteries of even the dreaded tuberculosis and the less dreaded common cold will be solved.

From these various illustrations you can come to the conclusion that a foreign substance which interferes with the normal functioning of the body is a cause of disease. A common cause of disease is the toxin produced by a bacterial parasite.

Ewing Galloway

FIG. 361. EDWARD JENNER, *a Physician who investigated an Opinion expressed by a Milkmaid* (*1749–1823*)

TWO HUNDRED YEARS AGO a man with an unscarred face was unusual. Kings carried pockmarked smiles above their noble robes. Smallpox was a disease so widespread that doctors thought it natural to all children, and smallpox epidemics had occurred since early history · Ever since he could remember, Edward Jenner had wanted to be a doctor. Apprenticed to a surgeon at thirteen, he saw many cases of smallpox. One day a woman told him she was unafraid—had she not had cowpox? Jenner had already heard this statement many times. He wondered if there could be any truth in it. Was there indeed a relation between cowpox, which harmed no one, and smallpox, which killed thousands? A few years more and young Jenner had become a country doctor in his home town. He was popular with his patients and won a reputation as a skillful surgeon. The problem of smallpox was still before him. Dairymaids caught cowpox from the cattle, had a few sores, and never got smallpox. Could he deliberately give a patient cowpox to prevent his having smallpox? In 1796 he tried it. He scratched the arm of a patient, put in a bit of matter from a pox sore,—and the patient had cowpox. Later, when exposed to smallpox, he did not get it. This was more than a hundred years ago. Today vaccination is insisted upon in many places. Smallpox epidemics have disappeared from civilized countries because a country doctor investigated an opinion expressed by a milkmaid.

D. Shall we take Medicines?

The common method of treating illness is to take medicines. This treatment was used by primitive men as far back as one can trace history. It is used today, often with no more intelligence than it was used in earlier times. The eagerness of man to regain health when ill has led him to try many things. As a result of these many trials, substances have been found which will produce certain well-known effects on the body. There are narcotic drugs that kill pain; there are other drugs that act as stimulants. But when you recognize that the cause of illness is a disturbance of normal functioning, it is hard to see how a medicine can correct the difficulty.

Self-medication may be ineffective and dangerous

Yet our faith in medicines seems to be firmly rooted. This faith, handed down to us from our forefathers, finds but little support from modern science. It seems indeed to be disgracefully exploited by unprincipled advertisers, with the result that people are led to take worthless mixtures as treatments for serious disorders. At the same time others are led to take dangerous substances for medicine when they need nothing at all. Many of the complaints of man are associated with ailments which are but products of his own imagination.

Alcohol is a narcotic

Alcohol is a typical narcotic drug. When taken even in small quantities it slows up the normal functioning of the body. In large amounts it produces complete insensibility and death. The effects of alcohol in small and in large amounts have been carefully studied, and there is little or nothing that can be said to support its use. A typist works more slowly and with less accuracy after drinking; a rifle-shooter is less accurate in his aim; a bookkeeper is less accurate in adding a column of figures. Similarly it has been shown that ability to memorize and to reason is reduced while a person is

even to a small extent under the influence of alcohol. There seems to be no scientific support for the belief expressed by some people that alcohol improves their ability to think. There are stories of great works in literature and in music that have been produced by artists while under the influence of alcohol. It seems likely that most of these stories are not true. There can be no doubt that alcohol affects normal functioning of the body. Similarly there can be no doubt that the effect in most cases is to reduce the efficiency.

Alcohol has been used extensively in medicines. In fact, it has in the past been a favorite household remedy and has been used in the treatment of most of the common ailments. Careful studies show that it is actually harmful in most of the cases in which it has been used. Physicians of today have very little use for alcohol in the treatment of disease.

Nicotine is a stimulant

The nicotine of tobacco is a stimulant, and its effects may be readily observed. It causes an increase in rate of heartbeat and an increase in blood pressure. In moderate amounts these effects are mild and may not be serious. The user of tobacco should know, however, that nicotine disturbs normal functioning. There is no reason to believe that this disturbance is in any way helpful.

Drugs and medicines, however, do have their place in the treatment of disease. There is a science of pharmacology (the science of drugs), and the physician draws upon this science in his prescription of medicine. Quinine is a cure for malaria, for it acts as a poison to the tiny parasites that feed upon the red blood corpuscles. Chaulmoogra oil is of use in the treatment of leprosy. There are medicines that will clear the intestine of tapeworm and hookworm. These treatments should be given following the advice of a physician.

Thus one cannot say simply, Do not take medicines.

It depends upon circumstances. There may be times when a stimulant is needed. There may be other times when a narcotic is needed. In cases of constipation a cathartic may be necessary. It should be remembered, however, that in all cases of illness self-medication, that is, prescribing one's own medicine, is likely to be not only ineffective but very dangerous.

E. What are Some of the Problems of Healthful Living in a Modern Civilization?

As you have seen, science has done much to make living healthful and safe for everyone. As you may see a little later in this unit, people generally have taken advantage of many of the results of scientific experiments to secure for themselves a healthful environment in terms of such factors as providing a pure water supply and getting rid of waste. Yet even by the best types of organization a community cannot guarantee fully a man's personal health. Much of this has to be taken care of by the individual himself. What do we mean?

Proper diet is an important factor in health

Once upon a time, as you have read in the early part of this book, man's diet presented a comparatively simple problem. As someone put it, the only problem was whether he ate or did not eat. But as the result of much work over many years man today is able to choose from a variety of foods. An attempt to order a meal from a restaurant menu or even to purchase wisely from neighborhood stores raises many problems tied up with knowledge of diets and their effect upon the human body. You know that certain types of food substances are necessary for good health. You know that some of these substances are present to a greater degree in some foods than in others. Do you, then, select your own foods in the cafeteria, for example, so as to secure a well-balanced meal, or do you select them in such a way

as to overload your system with one particular substance? This is your individual problem.

A plentiful supply of fresh air, sunshine, and exercise was once the least of man's worries. His food was secured by hunting. Later his work was agricultural. But today life is different for many people. They live in heated homes and work in heated offices and factories. Under such conditions man needs to consider carefully the program by which he shall secure his share of fresh air, of exercise, and of sunshine.

The human organism needs fresh air, sunshine, exercise, and rest

The life people live today, moreover, often makes it difficult to secure proper rest. Active days, late hours, and insufficient sleep are not likely to lead to the best possible health. From the study you have made of the human organism you should realize that it cannot continue to function indefinitely without opportunities to slow down and rest. Do you secure sufficient sleep?

With the increasingly complex nature of civilization has come the demand for greater alertness. The accident toll of this country is increasing startlingly. Almost a hundred thousand people a year die as the result of accidents — many more than from diphtheria, typhoid, yellow fever, and malaria combined. Why should this be? Part of the answer, of course, lies in the increasing use of machines. Automobiles, industrial machines, railroad trains, airplanes, — all contribute to this death rate. But as one examines the causes of accidental death, one is struck with the fact that a great percentage of it is due to individual carelessness. Consider the causes illustrated in Fig. 362. An adult drives a car across the railroad track without heeding the stop-look-listen signal. A child is a few minutes late for school and dashes across the street against a red light. A worker in an industrial plant was out late the night before, his nervous reactions are not as rapid as they should

Accidents are more common in a complex civilization

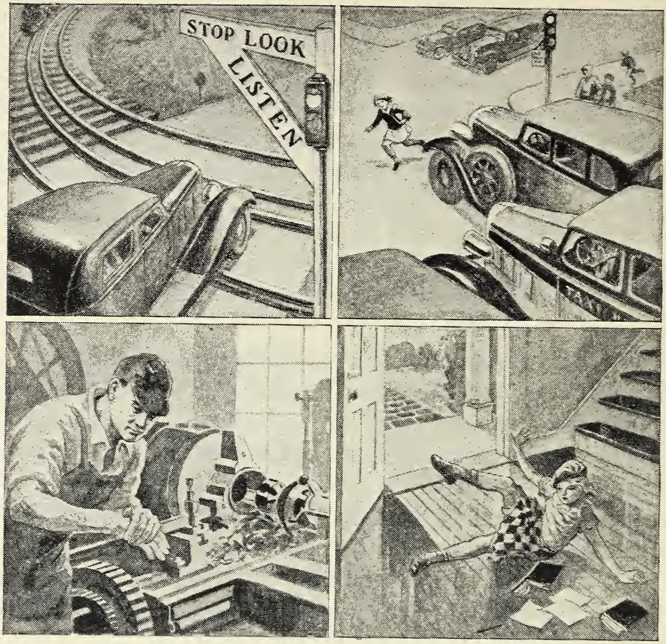


Fig. 362. A Great Percentage of the Accidents in this Country are due to Carelessness

What other items should you add to those shown here?

be, and a piece of automatic machinery catches his finger or his hand. These things are difficult to guard against by automatic means. The responsibility becomes the individual's. How well do you accept your responsibility? What unnecessary chances have you taken within the last few weeks?

Finally we come to one of the most important causes of ill health: the refusal of the individual to take advantage of the knowledge opened up by science. In spite of proved evidence you may know of persons whose medicine cabinets at home are filled with patent medicines for every imaginable sort of illness. Your elders probably know of other persons who are perfect bores because they insist upon tak-

ing every occasion for telling everyone of a new remedy they have found for some imaginary ailment. Are such people taking advantage of scientific knowledge?

Good health depends upon intelligent use of known information

In the end, then, good health depends to a great degree upon the intelligent use by the individual of knowledge at hand. Science has pointed out how a normal human body functions, how this functioning may be disturbed, and in part how this disturbance may be corrected. Sometimes, of course, it is impossible to restore the body to a condition of perfectly healthy action. Many times, however, the reason why this is not achieved lies with the individual and not with society.

In good health the condition of the body is found to be a nicely balanced functioning of all the bodily organs. Ill health comes when this balance is disturbed. Such disturbances may come from different sources, many of which are due to the pressure of living in a complex civilization.

Can You Answer these Questions?

1. What are five general causes of disturbance in normal functioning of the human organism?

2. Make a list of different substances contained in the blood.

3. Why are the glands of internal secretion so important?

4. What is an important function of the red corpuscles? of the white corpuscles?

5. Are bacteria plant or animal parasites? Are protozoans?

6. Why is hookworm disease called a filth disease?

7. What is a toxin? an antitoxin? What supposition underlies the treatment of bacterial diseases by the use of antitoxins? How is the antitoxin for diphtheria produced commercially?

8. What evidence is there that alcohol is a narcotic and tobacco a stimulant?

Questions for Discussion

1. How does your community rank in health in comparison with other communities?

2. Should you agree or disagree with someone who said that man still practices many of the healing arts today which were common thousands of years ago?

3. Do you think that the process by which antitoxin is produced from healthy animals is a cruel one?

4. Could we get along without medicines? Support your answer.

Here are Some Things You May Want to Do

1. Read in De Kruif's *Microbe Hunters* the stories of the conquest of malaria and of yellow fever. Report on them in class.

2. See what you can find out about the life and work of some health workers, such as Robert Koch, Lord Lister, Hideyo Noguchi, Edward Trudeau, and William Gorgas. Write short biographical sketches about them.

3. Make a special study of accidents in your community. Which are the most common? What can you do to cut down the accident rate? How does the accident rate of today compare with that of ten years ago?

4. Are people today still superstitious about health? Make a list of superstitions which you know and explain why you think each one you include is a superstition and not scientific knowledge.

5. If there is a microscope in your science laboratory, examine a drop of blood and find the red and the white corpuscles.

6. Look through some magazines and newspapers and see how many advertisements appear which claim that certain products have value as medicine. Check radio programs for a week and see how many so-called "remedies" are advertised there. To what extent are these advertisements dishonest?

7. Make a list of medicines known to have value as cures.

8. Test a number of medicines with litmus paper. Which ones are acid, which are alkaline, and which are neutral? Dissolve dry medicines in water and test the solution.

Chapter XXVII · How does Man control the Condition of the Air Indoors?

How well do you recall some early spring days? The sharp chill of winter is gone. The temperature may range between 65° and 75°. The rays of sunshine once more seem warm as you bask in them, comfortable and content. A gentle breeze may be blowing. Such a day, you may say, is nearly perfect. It is neither too hot nor too cold, too dry nor too damp.

Why does such a day seem so comfortable? Among other things the condition of the air seems just right. Contrast such a day with one in hot summer. The air is warm and damp. Every piece of clothing seems moist. It is an effort to move. Not a bit of breeze is stirring. Or think of a day in winter. Ice is thick on ponds and streams, and animal life has sought shelter. The cold seems to cut to the bone.

Because of these contrasts man has tried in many ways to maintain indoors through winter and summer the conditions similar to those in the out-of-doors on a pleasant spring day. Many of these attempts have depended upon the use of machinery. Let us see what we can find out about them.

A. How do People affect the Air in which they Live?

You know something of the manner in which air is affected by the people in it. You may remember that three important factors must be considered: temperature, humidity, and the percentage of various gases which are present. Examine the effect of people upon these factors. Heat is produced within the body as foods are used, yet the temperature of the body remains constant.

The heat produced by bodily processes affects the temperature of the air

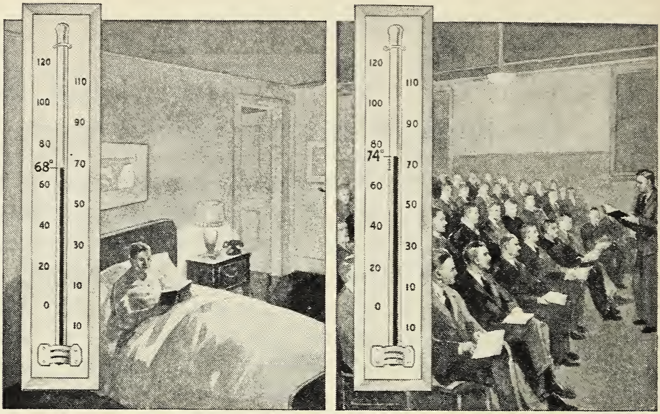


Fig. 363. Forty People sitting quietly in a Classroom will give off Heat Enough in One Hour to raise the Temperature of the Room about Six Degrees

Obviously the surplus heat must escape. Careful studies have shown that a normal person reclining quietly in bed releases about 300 B.T.U. per hour (75 kilogram-calories). In a sitting position about 384 B.T.U. (96 kilogram-calories) are released. Consider the heat losses from the bodies of people seated in a room. Can you recall the definition of B.T.U.? If you can, you know that 384 B.T.U. represent enough heat to raise the temperature of 384 pounds of water one degree Fahrenheit. This same quantity of heat will raise one degree the temperature of 96 pounds of air (equivalent to about 1150 cubic feet, since 1 cubic foot of air weighs about $\frac{1}{12}$ pound). A classroom for forty people contains about 8000 cubic feet. A simple calculation based on these figures will show that forty people will give off heat enough in one hour to raise the temperature of the air in such a room about six degrees. Fig. 363 shows this in vivid fashion. Normally, however, the room is ventilated so that air flowing out of the room carries the heat away.

In a crowded theater the problem of heat control is not simple. The amount of heat given off from a thousand people seems really enormous. Indeed it would be enough in one hour to raise the temperature of one ton of water from the temperature of ice to the temperature of boiling. Obviously air must circulate freely through such a crowded room if the occupants are to be kept comfortable.

Now consider humidity. You know that water enters the air from the skin by evaporation. Normally about 2 quarts of water pass through the sweat glands in twenty-four hours, or at a rate of $\frac{1}{12}$ quart an hour. This rate, of course, varies with temperature and amount of exercise. A simple calculation shows that thirty-six people evaporate 3 quarts of water from the skin in an hour.

The humidity of air is affected by the evaporation of water from the body

A room of 8000 cubic feet at 70° F. and 50 per cent relative humidity contains water vapor equivalent to about 2 quarts of water. You may check this figure by the information in the table you have already used, showing the weight of water vapor per cubic foot when the space is completely saturated. If the space in the room were completely saturated at 70° F., it would hold a little more than 4 quarts of water. The water evaporated from the bodies of forty people in one hour would be, therefore, more than enough to raise the humidity from 50 to 100 per cent in a room of 8000 cubic feet capacity at a temperature of 70° F. The surplus would be an amount equal to 1 quart of liquid. In this small room it would be easy to control this extra humidity, for air circulating through the room would carry the water vapor away. However, it is not so easy in a large crowded room. One good reason for ventilating a crowded room is to control the humidity.

Now consider the oxygen content of the air. Normally (that is, at rest) we require about 1 pint of oxygen each minute. This is 60 pints, or about 1 cubic foot, of pure oxygen in one hour. Air, as you know, is about 21 per cent

oxygen. In a room of 8000 cubic feet capacity there are about 1680 cubic feet (21 per cent of 8000 equals 1680) of oxygen. Forty people would use only about 40 cubic feet of oxygen in an hour. If you could suppose that the room is tightly sealed, the percentage of oxygen would be reduced in one hour by only a very small amount.

Would this change have any effect upon comfort? As one molecule of oxygen is used in the body, one molecule of carbon dioxide is produced. Normally 8000 cubic feet of air contain about 3 cubic feet of carbon dioxide. If the room is sealed with forty people in it, the room will contain at the end of one hour 40 cubic feet more of carbon dioxide and 40 cubic feet less of oxygen.

How does this change affect the percentage of oxygen in the air of the room? By removing 40 cubic feet the total is reduced to 1640 cubic feet. The percentage is now 20.5, since 1640 is 20.5 per cent of 8000. In other words, the presence of forty people in this tightly sealed room for one hour will reduce the percentage of oxygen only 0.5 per cent.

Normal changes in the oxygen and carbon dioxide content of air have little effect upon bodily comfort

Consider now the percentage of carbon dioxide. It is increased from 3 to 43 cubic feet. At the end of one hour in this tightly closed room with forty people the percentage of carbon dioxide would be 0.54 per cent (43 is 0.54 per cent of 8000). Fig. 364 illustrates some of these conditions. Experiments with which you may be familiar have shown that reducing the oxygen content to 20.5 per cent and at the same time increasing the carbon dioxide content to 0.5 (or even to 1 or 2) per cent does not noticeably affect the feeling of comfort of people in the room.

In what other ways may the air in the room be affected? Among forty people there may be a few who have "bad breath," owing to bad teeth or to some other condition of the mouth or of the stomach or the intestines. The odor

Fig. 364. Changes in the Oxygen and Carbon Dioxide Content of Air even in a tightly Closed Room have Little Effect upon Bodily Comfort

of bad breath comes from the mouth, not from the lungs. There may be some who are careless about bathing and who carry the odor of perspiration on their skin and clothing. The odors of a poorly ventilated room come chiefly from these two sources. In addition there may be diseased persons in the room; and they may, as they cough, sneeze, or even talk, hurl into the air droplets of mucus carrying bacteria.

These effects are produced on the air of a room by people. You may see in what particulars it is unlike the air outdoors on a pleasant day in springtime. It is these factors affecting the air that we attempt to control by ventilation. Let us see now how these things are controlled.

B. What Effects from Heating or from Cooling Air are related to Health and Comfort?

If the outside temperature is at freezing, we appreciate a warm fire indoors. Before the heat is turned on, the air indoors is similar to the air out of doors. In a typical con-

dition, humidity in the out-of-doors may be 60 per cent when the temperature is at 32° F. You may see from a table showing the weight of water vapor at different temperatures in saturated space that a space is saturated at 32° F. when there are 2.113 grains of moisture in each cubic foot. If the space is 60 per cent saturated, it contains 1.2678 grains of moisture per cubic foot (60 per cent of 2.113 equals 1.2678). As the room is warmed, the temperature rises to, say, 70° F. Now it requires 7.980 grains of moisture to saturate 1 cubic foot of the space in the room. But the space contains only 1.2678 grains of moisture per cubic foot. Therefore it is but 15.9 per cent saturated. In other words, the effect from heating in this illustration is to lower the humidity from 60 per cent to 15.9 per cent. The air in heated rooms, when no moisture is added, is really very dry. Do you see why?

As air indoors is heated, its humidity is lowered

It is becoming common practice to cool a room in summer, just as it is common practice to heat it in winter. How is the humidity affected by cooling? Suppose it is a hot day with the temperature at 98° in the shade and with the humidity at 60 per cent. By simple calculation, using information from a humidity table, you may learn that a cubic foot of space contains 11.20 grains of water vapor when it is 60 per cent saturated. Suppose this air is cooled to 70°, as it would be in an air-conditioned motion-picture house. Recall that 1 cubic foot of space is saturated at this temperature with 7.98 grains of moisture. Obviously the surplus must precipitate, or condense. As it is cooled, each cubic foot loses about 3.22 grains and leaves the space saturated. If the air in a room of 10,000 cubic feet were cooled through the range from 98° to 70°, it would lose 32,200 grains of water. This is nearly 5 pounds, or more than $\frac{1}{2}$ gallon.

There are two other things that should be mentioned for their effects on the air we breathe. These are poisonous

gases and dust. Poisonous gases may have their origins in the gas that is used for cooking, in gases that escape from the furnace in the house or the furnace of a near-by factory, or in the exhaust gases from an automobile. Every reasonable precaution should be taken to keep the poisons out of the air. Dust is always present. Effort should be made to keep the amount as small as possible.

Keep in mind now the many things that must be taken into account in ventilation and in air-conditioning. Let us summarize them for you. The people in a room give off heat, moisture, and odors. For comfort the people demand a temperature of about 70°, and the most desirable humidity is 60 per cent. As air is warmed, its humidity is decreased; and as it is cooled, its humidity is increased. Since man has sought to control the features of his environment, what has he learned about controlling the condition of the air in which he lives much of his time, that is, the air indoors?

C. How are Houses Heated?

Heating a house may seem a rather simple thing to you. And so it may be — today. But the fact that people now may sit comfortably in well-heated schools, theaters, churches, and homes is but additional evidence of man's increasing control over his environment. Fig. 365 shows some steps in the history of this control. Let us look at some simple schemes for heating.

You may at some time have stood around an open fire out of doors or in front of an open fireplace. You know that at best this method of heating is not very satisfactory; for as you may have said, you roasted one minute and froze the next. Why should this be? Remember that this warmth of a fire gets to you chiefly by radiation and convection. Heat, as you may remember, is the kinetic energy of molecules. Since this is

The heat of a fire, which is really the kinetic energy of molecules, is transferred mainly by convection

Fig. 365. Modern Methods of Heating are the Result of Increasing Knowledge and Control

How many of the methods shown above do we use today?

so, it follows that the molecules of hot gases have higher kinetic energy than have the molecules of cool gases. You know, too, that a hot object gives off radiant energy and that the radiant energy produces heat. By application of this knowledge you can see that when you stand before a fire in the out-of-doors or before a fireplace you are receiving heat mainly from the radiant energy of the fire. Why? Look at Fig. 366. Convection currents are set up as shown, but the heated air is forced upward until it is lost in the upper air. Thus the heated air does not circulate so as to warm the person standing near the fire. With a fireplace the heated air is forced up the chimney.

FIG. 366. The Heat of an Open Fire is transferred mainly by Convection

How does a stove warm a room? Fig. 365 shows a stove. The less dense warm air is forced upward by the more dense cold air. Air over the stove is least dense, so the force of gravity forces air to flow toward the stove from all parts of the room. If there is no loss through cracks or doors and windows, the temperature of the air of the room will rise rapidly as the air flows toward the stove and upward. A stove is the most efficient heater in the sense that it will deliver more heat to the room from a pound of coal than any other heater in common use. The difficulty, however, is that it heats satisfactorily only one room. As houses grew larger, other ways of heating had to be found.

A common stove is a simple means of heating a room

The simplest type of furnace used is the hot-air furnace. This is similar to a stove. In Fig. 367 you see a cross section of such a plant. Notice the space round the fire box. The heat of the fire warms the air in this space, causing the air to expand. Notice, too, the pan of water

Fig. 367. The Operation of the Hot-Air Furnace is based upon the Principles of Convection

to supply moisture to the heated air. In one type of furnace the heated air flows to various parts of the house through a system of pipes; in another type the top of the hot-air space is placed level with the floor of a room on the ground floor of the house, and the heated air flows into the room and circulates through the entire house. While this type of furnace has certain advantages, they are outweighed by definite disadvantages, especially in a large house. The heated air cools very rapidly as it leaves the hot-air box, with the result that upper-floor rooms are cold. Then, too, the registers through which the heated air reaches the room furnish excellent openings for dust and

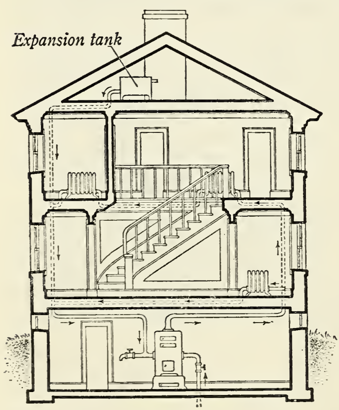


Fig. 368. Convection Currents in Water distribute Heat through the Radiators of a Hot-Water Heater

dirt. In spite of these disadvantages, however, many such plants are still in use, since they are both economical and simple to operate.

Convection currents in water distribute heat through the radiators of a hot-water heater

Another system is of the hot-water type, as shown in Fig. 368. Here the furnace, instead of heating air, heats water. The hot water is less dense than cold water, so the hot water is forced upward and into the radiators by the denser cold water that flows to the furnace through the return pipe. Heat keeps the water flowing through the radiators as convection currents rise. The pipes lead to radiators in the various rooms. A radiator, usually made of iron, offers, as you can see from the cross section in Fig. 369, a large area of heating space. As the hot water flows through the radiator, heat is transferred by conduction, is radiated into the room, and is carried around it by convection currents.

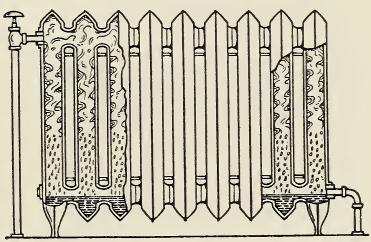


Fig. 369. A Radiator is so constructed as to offer a Large Area of Heating Space

Certain precautions are necessary with this type of furnace. Obviously water must be provided at all times. Moreover, if the fire gets too hot, the water changes to steam. Notice that in Fig. 368 a box called an expansion tank is shown in the attic. As the water is heated, it expands. The expansion tank is connected with the pipes. As the water expands, the extra water flows into the tank.

There is still one other common system of heating, shown in Fig. 370. We refer of course to steam heat. The furnace used here is of a slightly different type. It resembles the boiler of an engine. In practice this boiler generates, or produces, steam. The cold radiator, full of air, is warmed as steam from the boiler forces the air out through a valve.

Today many homes are equipped with furnaces which seem almost automatic. The drafts are controlled by a thermostat which opens the draft as the house gets cooler and closes the drafts as the house gets warmer. Fig. 371 shows the structure of a thermostat. The bar within it responds to changes in temperature. This bar is made by fastening together strips of two different metals. Metals expand and contract when heated and cooled. Two metals are chosen that do not expand and contract at the same rate. You may illustrate this with a compound bar like the one shown in Fig. 372. It is really a bar of iron welded to a bar of copper. Copper expands more than iron. When the compound bar is heated, it curves with the copper on the outside of the curve. As it is cooled, the curve straightens. In the curved bar of the thermostat the metal on the outside of the curve changes more for an equal change in temperature than does the metal on the inside of the curve. Thus it pushes the straight bar toward the left as it is warmed, and toward the right as it is cooled.

The principle of the thermostat is explained by the different rates of expansion of different metals

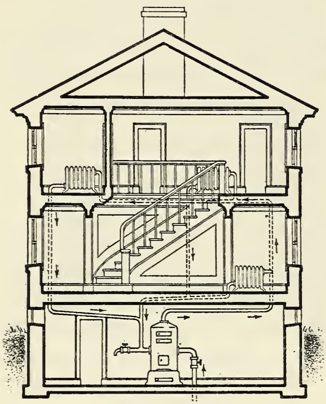


Fig. 370. In the Steam-Heating Plant, Steam carries Heat to the Radiators

What are the essential differences between such a system and a hot-water system?

A thermostat is sensitive to small changes in temperature, as you can find out by some simple experiments. The one shown in Fig. 371 is connected to a battery and a motor. When the room has cooled to the temperature for which the thermostat is set, the straight bar touches the point on the

left. This contact carries current through the motor and opens the draft of the furnace. As the room gets warmer, the curved bar pulls the straight bar to the right. When the contact is made, it again turns the current through the motor, but this time in such a way that the motor closes the draft of the furnace. In other words, the thermostat causes the draft to open and close in order to keep the room at the proper temperature.

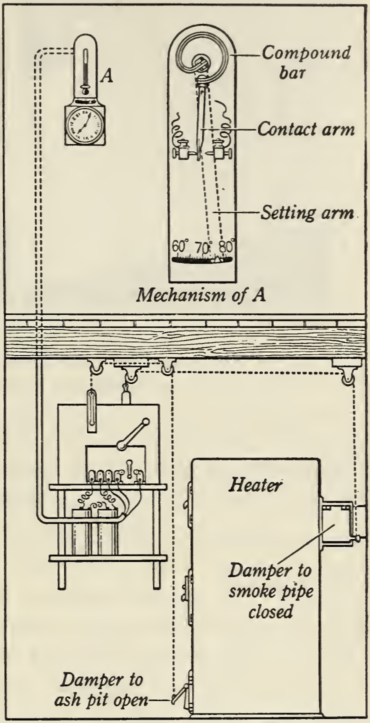
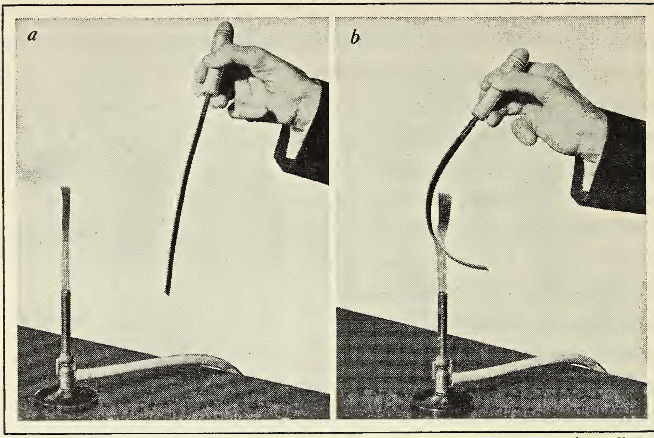


FIG. 371. A Thermostat applies the Principles of a Compound Bar for the Automatic Regulation of Temperature

Can you now explain how a thermostat works?

During the day you may keep the thermostat set for 68°. Ordinarily you do not wish to keep the house so warm through the night, 50° probably being as much as desired. A clock attached to the thermostat may be set so that just before getting-up time it will set the thermostat back to 68°. In a modern oil-burning furnace this change will turn fuel into the furnace and set the drafts. By getting-up time the house will be comfortably warm. This little control has added enormously to man's comfort.

Now consider the fuels used for heat. Most common, of course, is coal. Another type of fuel, however, is rapidly coming into use. Many homes are now equipped with



Ewing Galloway

Fig. 372. A Compound Bar may be used to illustrate the Different Rates of Expansion of Different Metals

Why should a bar (*a*) bend (*b*) when heated for less than a minute?

oil-burners, which use a heavy and comparatively cheap type of fuel oil. The machines are, in general, of two types. In one (see Fig. 373, *a*) the oil is changed into vapor and fed through a gun nozzle. In the other type (see Fig. 373, *b*) the oil is fed to a rotating plate which throws the oil in a circle around the fire box.

Several different types of fuel are used for heating

In any form of heating, convection currents distribute the heat. The walls of houses are not air-tight; so convection currents seep through. The force of the currents in a particular house depends most upon the difference in temperature between the air indoors and that outdoors. Ventilating engineers have figured from measurements the rate at which air passes through the walls of a house under varying conditions. How fast do you think air changes in an ordinary well-built house when the temperature indoors is

In the ordinary house the air changes rapidly in the cold weather because of leaks through the walls and through crevices

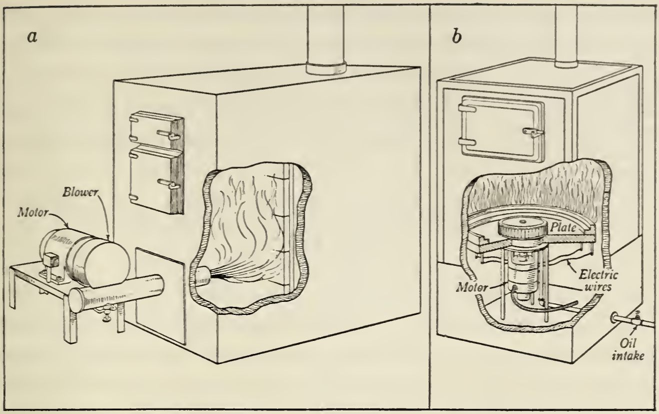


FIG. 373. In General, Oil-Burners are of Two Types, (*a*) the Spray and (*b*) the Rotary

What are the essential differences between these two types?

70°, the temperature outdoors is 0°, and doors and windows are tightly closed? According to estimates air passes through walls and crevices of an ordinary well-built house fast enough to accomplish a complete change of air every hour.

It is comparatively easy to heat the air, but heating alone does not make the air of a cold winter day like the air of a pleasant spring day. As you have already learned, the humidity of heated air is often below the standard recognized as best for health and comfort. This condition presents another problem.

D. How is Humidity controlled in Winter?

The general principles of humidity control are simple enough, but the practical difficulties are not easy to overcome. Consider, for example, an ordinary six-room house of 10,000 cubic feet capacity. Earlier in this chapter you learned that heating air of 60 per cent humidity from freez-

ing (32°) to 70° lowers the humidity to 15.9 per cent. How much water would be required to raise it again to 60 per cent? Air at 70° and of 15.9 per cent humidity contains 1.269 grains of water vapor per cubic foot. For convenience let us say 1.3. Air at 70° and of 60 per cent humidity contains about 4.8 grains of water vapor per cubic foot. To raise the humidity from 15.9 per cent to 60 per cent requires therefore the addition of 3.5 grains of water to each cubic foot if the temperature is kept at 70°. When the temperature outdoors is at 0°, the air in an ordinary well-built house will change, as you will recall, once an hour. Let us suppose that with an outdoor temperature of 32° and an indoor temperature of 70° the air in the house will change once in two hours. In this case 120,000 cubic feet of air will pass through a house of 10,000 cubic feet capacity during a day. For each cubic foot, 3.5 grains of water are required to raise the humidity from 15.9 per cent to 60 per cent. This is 420,000 grains of water, equal to 60 pounds, or about 7½ gallons. The practical difficulties connected with evaporating 7½ gallons of water in a day are considerable.

The lowering in humidity due to overheating is so great that it cannot be restored by simple methods

You may see from these facts the uselessness of placing a pan of water on the radiator. The so-called humidifiers sometimes used as attachments to radiators and hot-air furnaces are equally useless. At best not more than a few quarts a day will evaporate from them.

There are other practical difficulties. Suppose you could cause enough water to evaporate to bring the humidity up to 60 per cent, that is, up to 4.8 grains per cubic foot. What are some of the things that would happen? The temperature through the house is not uniform. The windows and outside walls are colder than the inside walls. If air with 4.8 grains of moisture per cubic foot were cooled to 50°, some of the moisture would precipitate. Under normal conditions of winter the windows and outside walls

might be at this temperature or lower. Therefore moisture would form on windows and walls and probably do damage to woodwork and plaster. In houses as they are commonly built the practical difficulties associated with maintaining proper humidity seem almost impossible to overcome.

E. How are Temperature and Humidity controlled in Summer?

On a hot day in summer, when the temperature is, say, 98° and the humidity at 60 per cent, we find ourselves very uncomfortable. It is easy to see why. The temperature of the air and the temperature of our bodies are nearly the same, but even while at rest we must get rid of at least 384 B.T.U. (96 kilogram-calories) an hour. Yet we may step into an air-conditioned theater and find conditions entirely comfortable. How are the conditions controlled?

In common practice air is forced into the theater through cooling coils like those used in refrigeration. You know that evaporation has a cooling effect. For cooling these coils a liquid which readily changes to vapor, usually ammonia, is used. At ordinary temperature, say 70°, and at normal atmospheric pressure ammonia is a gas.

One part of the cooling apparatus consists of a mechanism for compressing ammonia. As the ammonia is compressed, it gets hot. A second part of the apparatus is a mechanism for cooling the compressed ammonia. This may be done by pouring cold water over the pipes in which the ammonia is inclosed. A third part is a mechanism in which the compressed ammonia is allowed to expand. As it expands, it takes up from the surrounding region just as much heat as was carried away by the running water. If this heat is taken from the air in the room, the air is cooled in the process. Let us examine this cooling unit, as shown in Fig. 374, in a little more detail.

The temperature of a gas rises when the gas is compressed

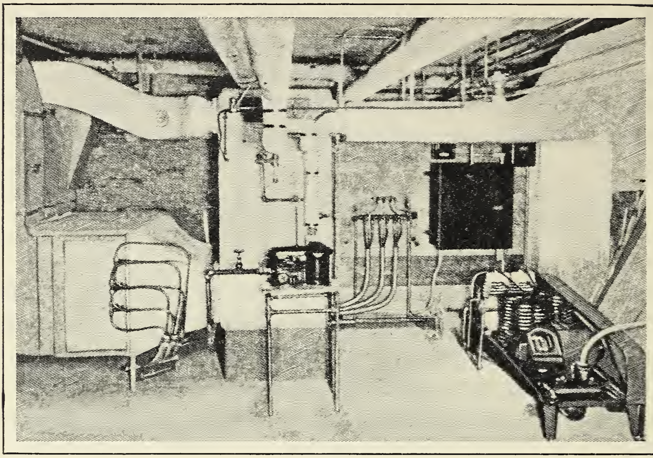


Fig. 374. The Operation of Commercial Air-Conditioning Plants may be explained through the Principle that the Temperature of a Gas rises when the Gas is Compressed

Suppose the ammonia at normal air pressure of 15 pounds per square inch is sent through a compressor and put under a pressure of 150 pounds per square inch. The volume of the gas is greatly reduced by the pressure. Recall again that heat is the kinetic energy of moving molecules. If a given amount of heat is brought into a smaller volume, the temperature in the smaller volume must be raised. Do you see, then, why a gas gets hot as it is compressed into a smaller volume?

As a matter of fact, the gas would get extremely hot if it were quickly compressed from a pressure of 15 pounds to 150 pounds. In practice it is compressed slowly, and the heat that is released is carried away in running water.

Ammonia is much used as a refrigerating agent because it changes to a liquid at a pressure of about 150 pounds and at a temperature of about 70° F. As it changes to a liquid, each gram of it loses about 300 gram-calories of heat. Other gaseous substances behave like ammonia.

By compression and cooling, a large amount of energy in the form of heat has been removed from the ammonia. Heat has been carried away in running water, and the ammonia is now in liquid form. It is inclosed in pipes, and the pressure on it may be 150 pounds per square inch at a temperature of 70° F.

The liquid may be pumped along in the pipes to any position in which it is to be used. Suppose it is sent to the cooling coils of a large air-conditioning apparatus, such as the one shown in Fig. 374. In these coils the pressure is reduced, and ammonia begins to evaporate. As it changes from a liquid to a gas, each gram of the ammonia takes up just as much heat as it lost in changing from gas to liquid. This amount, you will recall, was about 300 gram-calories per gram. This heat is removed from the air surrounding the coil. The ammonia takes up the heat from the space to be cooled. As the ammonia is forced along through the compressor and cooling mechanism, the heat it gathered is carried away by running water, and the cooling agent is again reduced to a liquid. Thus ammonia takes heat from the air of an air-conditioned room and releases it to running water.

As ammonia is compressed and cooled, and again allowed to expand, it takes up heat from the surrounding air

F. What are the Possibilities of Air-conditioning?

We have reviewed now all the important factors influencing the conditions of indoor air, and we have reviewed the principles that may be applied in accomplishing control of these factors. It seems possible to maintain indoors through the cold of winter and the heat of summer conditions similar to those in the out-of-doors on a pleasant spring day. It is done in some railroad cars, in theaters, and in some other structures. It seems likely that a development lying just ahead is the application of air-conditioning to homes. But before air-conditioning can

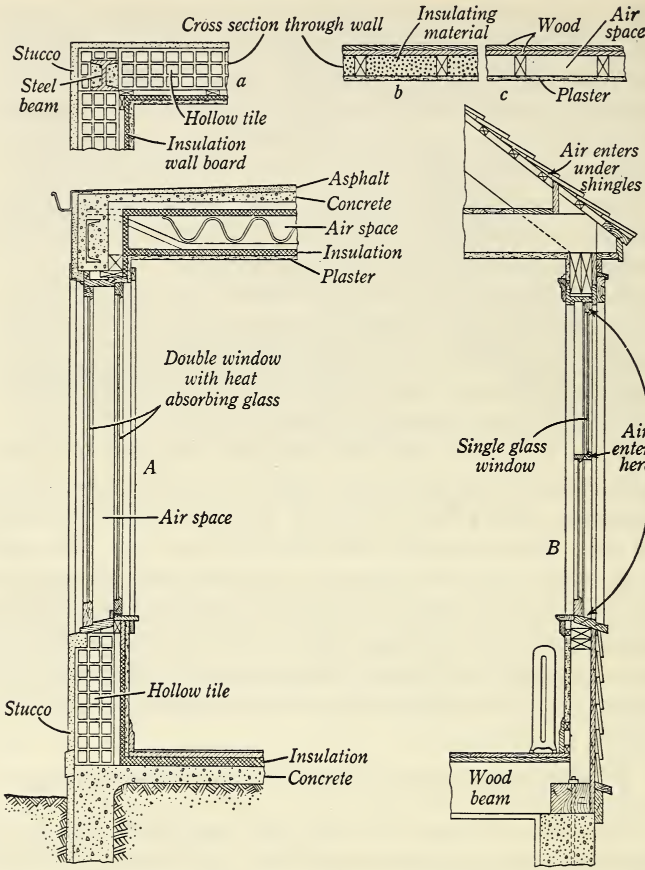


FIG. 375. Why is Complete Air-Conditioning Possible in a House constructed as in *A*, but Impossible in a House constructed as in *B*?

become practical for homes, a new type of construction must be used in home-building. Perhaps Fig. 375 will show why this is necessary.

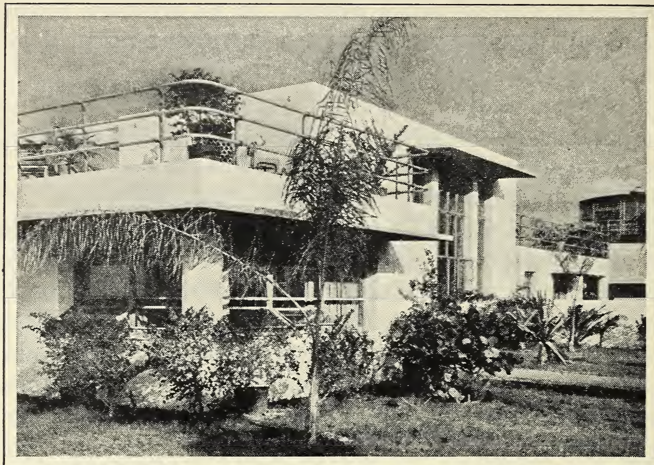
The air-conditioned home must be built so that it is nearly air-tight when doors are closed. Windows will be sealed and used only for light. The walls can be made of

sheet metal with all joints welded. In an ordinary house, as you will recall, there may be a complete change of air every hour when it is severely cold outside. In a house of sheet metal there would be no noticeable loss of air by convection, for air cannot pass through the walls. What about loss by radiation? Metals are good conductors of heat, so there would be loss by conduction and radiation unless provisions were made to prevent it. Loss from this source would be reduced considerably through the use of double walls. There might still be loss from conduction and radiation through the glass of the windows. As a result vapor would form on the inside of the glass during cold weather and on the outside during hot weather. Do you see why? To prevent this loss of heat and at the same time to prevent the fog on the windows, double windows with air space between them would be used. Why would this help, do you think?

By the present method of constructing homes air-conditioning is made an impracticability

In such a structure air-conditioning would be a relatively simple matter. In winter, air would enter through hot steam pipes which would raise the temperature to the desired point. The air could then be passed through a spray of water, which would contribute the moisture necessary to maintain proper humidity. At the same time it could be passed through a filter that would remove most of the dust. A fan might be used to circulate the air about the room. The conditioned air is not allowed to escape. True, it gathers the heat as well as the odors released from the bodies of people in the house, and the gases released from the cooking of food and from respiration. But in air-conditioning, these objectionable features are removed by washing the air with water.

A picture of a house designed for the new age is shown in Fig. 376. The walls may be made of welded sheets of iron or aluminum and be reënforced with concrete. This house is insulated so as to keep out the heat of summer



Ewing Galloway

Fig. 376. Air-conditioning may be as Common in Houses designed for the New Age as Heating is in the House of Today

Should you like to live in such a house? Why?

and the cold of winter. The insulation also prevents noises from entering, thus relieving nervous strain. Since it is air-conditioned, no screens are necessary, for the windows are never opened. The house is nearly free from dust, for only filtered air enters it. The "parts" of such houses will be built in factories and be shipped to the place where the house is to be set up. It will be assembled by putting the parts together. Such developments as these are without doubt possible, and we shall certainly see a rapid expansion of the air-conditioning industry.

Newer methods of building may open new possibilities for advance in air-conditioning

How will air-conditioning affect health? In the United States it probably is not important for health, although it may be more important than is now realized. We want it for comfort. We want our houses so that when we go indoors in winter we may be comfortably warm and so that when we go inside in summer we can be comfortably cool.

It may be interesting to consider what influence air-conditioning may have on civilization in the tropics. Regions suitable for rich agricultural development are at present undeveloped because of the heat. Suppose it were possible to go inside and get cool, just as it is now possible to go inside in the North and get warm. With air-conditioning and the applications of sanitation the torrid zone might be less objectionable as a place of residence. Perhaps there are new frontiers in many lands now thought uninhabitable.

Three factors—temperature, humidity, and the percentage of certain gases present—influence the condition of air. These factors are controlled by air-conditioning.

Can You Answer these Questions?

1. What important conditions of the air must be considered in deciding whether it is satisfactory for comfortable living? What effect do people have upon these conditions?

2. Why is the air in homes in winter, even though warmed, often unsatisfactory for comfortable living? What can be done about it?

3. How does raising or lowering the temperature of air affect its humidity?

4. What is the relationship between the kinetic energy of molecules and heat?

5. How may we apply the principle of convection currents to explain the operation of hot-air, hot-water, and steam-heating plants?

6. How may the operation of a thermostat be explained?

7. What are some of the practical difficulties which make full air-conditioning of the ordinary home almost impossible at the present time?

8. What principle concerning the action of gases under pressure may be used to explain the action of commercial air-conditioning plants?

Questions for Discussion

1. Does an electric fan really cool the air?

2. Why does frost seldom form on double windows?

3. Which should you say is the most important factor in providing comfortable air conditions in a home: temperature, humidity, oxygen content of the air, or carbon dioxide content of the air?

4. Many people believe that a hot-water heating plant is better than a steam-heating plant for providing satisfactory heat. What do you think about it? What are the merits of each?

5. What are the relative advantages and disadvantages of coal and oil as fuels?

6. Do you think that a small, portable air-conditioning plant for single-room use is satisfactory as a means of providing comfortable air conditions?

7. What do you think the possibilities are for air-conditioning in the tropics?

Here are Some Things You May Want to Do

1. Investigate your home or school heating systems and show by diagrams how heat reaches the various parts of the building.

2. Pretend that you are an oil-burner or air-conditioning-plant salesman. Get your facts together and give a sales talk to your classmates. Be sure your talk is of the scientific type.

3. The cooling principles described in connection with air-conditioning plants are also used in electric refrigerators. Make a study of these and explain their operation by means of an illustrated lecture.

4. Read again some story of life in hot tropical lands and try to explain how differently the story would have been written had the homes in the region been air-conditioned.

5. See if you can hook up a compound bar, two dry cells, and an electric bell in such a way as to demonstrate the principles of a thermostat.

Chapter XXVIII · How is the Health of the Community Controlled?

How well do you know your own community, especially with reference to the manner in which it protects the health of its citizens? Perhaps a few suggestions may provide the starting point for study and discussion. Do you have the facts which would enable you to answer satisfactorily the following questions?

How well do we control contagious diseases?

What rules and regulations do we have for the protection of water and food supplies?

How sanitary are our methods for disposing of garbage and sewage ?

Do we maintain laboratories in which studies and experiments may be carried on to further health protection?

Do we spend any money for the health training of our people?

Do we have a satisfactory system for recording births and deaths?

How does our community compare with other communities in its death and illness rates?

Can you answer these questions? Do you think that they are sufficiently important for you to spend some time on them? Perhaps you and your teacher can work out a plan for gathering information concerning them.

Notice that in each case we have used the word *we* rather than *it* or *the community*. What we are trying to suggest is that every individual in a community has a responsibility for seeing that satisfactory standards of health protection are maintained. The reasons for this suggestion are easy to see. In matters of health we depend in many ways upon the community in which we live. In a large city we do not know where our food comes from or the conditions under which it was pro-

The health of a community depends upon the individual as well as upon organized agencies

duced. As individuals we cannot control the water supply, nor can we alone take care of garbage or sewage disposal. These and many other matters of health and sanitation are controlled not by individuals working alone but by the individuals of a community working together. Because of the many things to be done, nearly every community maintains a board of health. We depend upon the members of such a board to use the authority of law in the enforcement of such measures as are necessary for the protection of our health. But as individuals we may coöperate and make their work more effective. And it is the right, in fact the duty, of every person to demand that public officers live up to their responsibilities.

Obviously, community sanitation is extremely important. If there were no control, we might without our knowledge purchase foods that were poisonous. Besides, sewage carrying germs of disease might get into our water supply and cause the spread of dangerous diseases through the community. These possibilities suggest some of the problems associated with maintaining the health of the community. There are many others. Let us see the relationship of science to some of them.

A. How is the Food Supply Controlled?

When you visit a meat market again, see if you can find any evidences of the work of health officers. Some indications of such work are obvious. Notice that the meat is displayed under glass, as shown in Fig. 377. Flies and other insects cannot get to it. Careless customers cannot touch it. Cooling coils extend through the case and keep the meat always cold. Perhaps the butcher may let you go into his storage rooms. There you will see beef and pork kept under such conditions as will guarantee their being suitable for human use. You would not stay long in this room, for its tempera-

Low temperatures aid in preserving food

Ewing Galloway

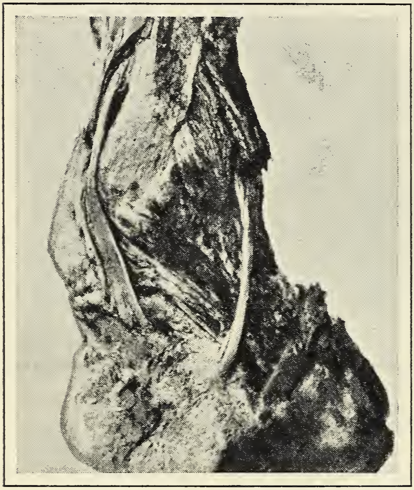
Fig. 377. The Modern Meat Market preserves its Food by the Application of Scientific Principles

What evidences of this do you see in the picture?

ture is just about 32° F. The problems of preserving food are not simple. Conditions satisfactory for beef are not satisfactory for fish, for fish must be kept at a colder temperature. Oysters, clams, and other sea food must be kept under still other conditions. Careful studies have been made to determine conditions under which meats and other foods should be kept. Regular inspection by a health officer guarantees that these conditions are maintained.

Why are such precautions taken? Meats left exposed to warm temperatures soon spoil, chiefly because of the action of bacteria and other fungus plants, including yeasts and molds. These organisms develop from tiny spores which are carried by the air. They may settle on the meat, on which they grow and from which they take food. As they feed upon the meat, they cause it to spoil. As it spoils,

poisonous substances with foul odors are produced. Dangerous consequences may follow eating spoiled meat. At the temperature of the storage rooms, however, these fungi do not grow, and the meat remains fresh indefinitely. Striking observations of the effectiveness of cold in preserving meats have been made in the discovery of animals found frozen in the ice of the Far North (see Fig. 378). Here animals killed by accident have been found frozen in the ice, where they have been for as long as several thousand years. Yet their flesh was in about the same condition as when the animal was killed.



Smithsonian Institution

Fig. 378. Cold protects against Decay

This is flesh of a mammoth that was frozen in ice probably for several thousand years

The work of health officers began long before the foods reached your market. If you will examine the beef, pork, and mutton hanging in the storage room, you will see that they are all plainly stamped "U.S. Inspected and Passed." What does this mean?

Farm animals were shipped alive to one of our larger cities. When the animals were killed, a government inspector was at hand to see that they were healthy. Beef cattle were inspected especially for tuberculosis. Pork was inspected for an infection known as trichinosis. This disease is caused by a parasite that lives in the muscle cells of the animal. The bodies of diseased animals were removed and burned. Thus the stamp on the meat assures us that

the inspector (and really the government itself) has found that the meat is good for food. In Fig. 379 you see such an inspector at work.

In the buildings where the animals are killed certain standards of sanitation must be maintained. The health officers must grant permits before the buildings can be used at all. Other standards apply to such features as lighting, plumbing, washrooms for workers, cleanliness of the workmen, and many other factors. Every precaution is taken to guarantee that the meat which comes to your table is good to eat.

The production of meats and other animal food is guarded by high sanitary standards

There is real need for the protection we get from government inspectors. Since it is expensive to maintain all these sanitary measures, dealers concerned only with profits are tempted to use unsanitary methods. Chemicals could be used to keep meat, and in appearance it would seem wholesome. Such chemicals present great dangers to public health, however, and government inspectors do not permit their use except under carefully controlled conditions.

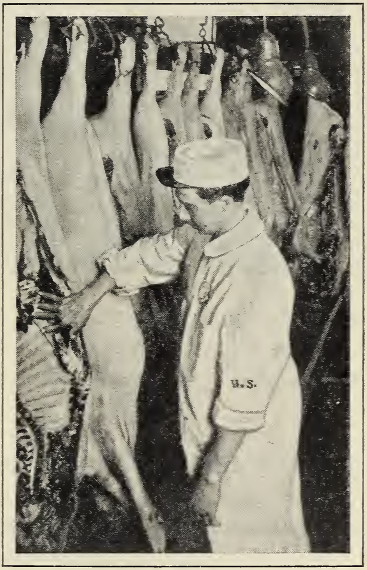


Fig. 379. Careful Government Inspection protects the Food that we Eat

Let us look at some other sources of food. In the grocery you find canned goods, fresh vegetables, bread, and pastries. Why are foodstuffs sealed in cans? Obviously

it is to protect them against the action of bacteria. Take tomatoes, for example. You will find only the finest ones used for canning. They are picked from the vines only after the tomatoes have thoroughly ripened. They are first heated for a short time in boiling water to loosen the skin, so that it may be easily removed. At the same time many of the bacteria which cause decay are killed. After the skins are removed, the tomatoes are placed in cans. In common practice the cans are closed except for a small opening. Then they are placed in the cooker. Cooking is continued in the cans at a temperature high enough to sterilize the tomatoes completely. The cans are now removed from the cooker, and the tiny hole is closed. The can, now free from bacteria and tightly sealed, is ready for the market. Such canned fruits and vegetables keep indefinitely. One of the steps in their preparation is shown in Fig. 380.

Canned foods keep indefinitely

Fig. 380. Canning is a Process by which Foods are preserved for Future Use

Here tomatoes are being inspected before they are canned

But there is need for government control in the canning industry too. Chemicals may be used in canning, to prevent growth of bacteria. Unwholesome or even dangerous articles treated with these chemicals may have the appearance of wholesome food.

If you will consider the importance of the health regulations we have discussed, you will see that as consumers, or

users, we must look to our government for protection against unprincipled practices. We must be assured from responsible government agents that the foods we buy from the grocery are good to eat. Let us follow more fully the care in preparing one staple of food for the market. If you could list foods in order of importance for health and well-being, it seems likely that milk would lead all others. What is milk? It is mostly water, but it contains fats, proteins, carbohydrates, and mineral salts. The proportions of the substances in a typical sample of cow's milk are as follows:

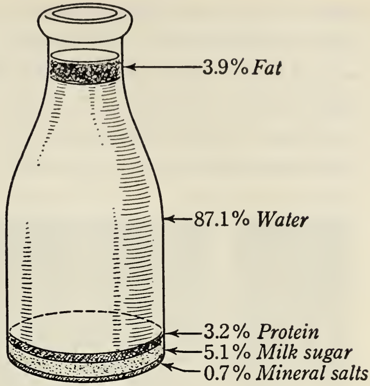


FIG. 381. Milk has Many Substances of Value for Proper Nourishment

Why should a substance containing such a large percentage of water have such great food value?

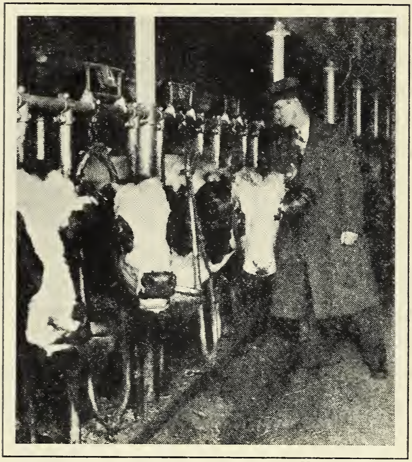
	Per Cent
Water	87.1
Milk sugar	5.1
Fat	3.9
Protein	3.2
Mineral salts	0.7

Perhaps Fig. 381 is familiar to you. In addition to these substances milk is rich in vitamins A and B.

You know something about the difficulties in keeping milk fresh. It is good food for bacteria and some other fungi as well as for people. Milk left exposed in warm weather soon sours. Observe some of the changes. Test some fresh milk with blue litmus paper and with red litmus paper. Blue litmus turns red in the presence of an acid. Red litmus turns blue in the presence of a base. You may see

The action of bacteria causes milk to sour

that neither blue litmus paper nor red litmus paper changes color in fresh milk. Obviously there is neither an acid nor a base in it. But leave the milk in a warm place for forty-eight hours. Possibly you may tell from the odor of it that it is sour. Test it again with red litmus and blue litmus. Now you may see that the blue litmus changes to red when placed in sour milk. If you will examine the milk with some care, you may see that it has curdled.



Ewing Galloway

Fig. 382. Dairy Cattle are examined at Regular Intervals to see that they are Free from Disease

The inspector is a government official. You should demand that he do his work well

What is the origin of the acid, and why does the milk curdle? Bacteria that get into the milk feed upon milk sugar and change it to lactic acid. This acid, like all other acids, produces a sour taste and turns blue litmus red. As acid forms, it causes the milk to curdle. The curd, or solid part, forms from the protein in the milk. You may demonstrate the fact that acid causes milk to curdle. Put some fresh milk in a test tube. Add a drop or two of dilute hydrochloric acid and notice that a curd forms. The bacteria that feed upon milk sugar and cause milk to sour and to curdle are not harmful. Doubtless you know that cheese is made from sour milk. Bacteria or molds growing upon cheese give it flavor. Different organisms give different flavors. The milk in cream is usually soured before the cream is made into butter. There are many harmless bac-

teria in every glass of milk that comes to the table. These harmless forms will multiply rapidly if the milk is warm and will cause milk to sour. If the milk is kept cold, these bacteria do not multiply rapidly and the milk will remain sweet for a long time. If all the bacteria and other fungi are killed, as is the case in canned milk, the milk will keep indefinitely.

Dangerous bacteria may get into milk through careless handling

Bacteria that produce disease may be present in milk. Cows may have tuberculosis, and the bacteria of tuberculosis may get into milk. Dairy cattle are examined at regular intervals, as shown in Fig. 382, to see that they are free from disease. The greatest danger, however, is from bacteria of disease that get into milk from the hands of people who themselves have disease. Many cases of typhoid fever have been traced to milk. Diphtheria and several other illnesses have been traced to the same source. Cows do not have typhoid fever or diphtheria, so these bacteria never are present in the milk as it comes from the cow. They get there from careless handling.

Milk is an extremely important food substance, and in the dairy every precaution is taken to bottle it in such a way that it will remain sweet for a long time and in such a way that bacteria of disease cannot get into it. Suppose we visit a dairy farm and see how this is done.

Notice that a dairy barn, as shown in Fig. 383, is very clean. The cows are regularly washed before milking. The milking itself is done by machines, and the parts of the machines are sterilized before the milking is begun. The workmen are dressed in white, and a fresh suit is used for every milking. Before handling the machinery the workmen very carefully wash their hands. The barn seems almost as clean as a hospital. Why so much care? It is by cleanliness that bacteria in milk are kept to the lowest possible number.

With all the care that may be taken, there are some bacteria in the milk. While the milk is warm, the bacteria

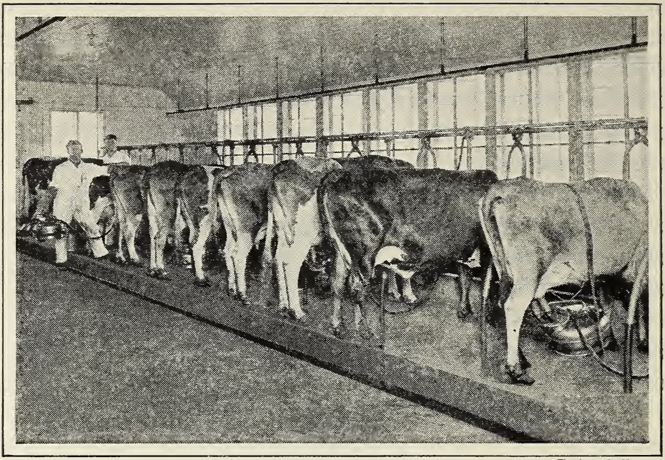


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Fig. 383. The Modern Dairy Barn is carefully protected against Unsanitary Conditions

Can you see any evidences of the Machine Age here?

develop rapidly; and unless care is taken, every bacterium that gets in at the time of milking will have produced several hundred within a few hours. If the milk is kept warm, it will not be many hours before bacteria cause the milk to sour.

Pasteurization kills the bacteria that cause disease

The temperature of the milk as it comes from the cow is the same as that of the cow's body, and that is about the same as the temperature of your body. Bacteria flourish in this warm milk. As soon as taken from the cow, then, the milk is cooled; and as soon as possible it is started on its way in refrigeration tanks (as shown in Fig. 384) to the pasteurizing plant. This is usually in the city, and milk from several farms may come to it. Why is pasteurization necessary after so much care? It is simply an added measure to keep bacteria under control.

The process of pasteurization is one in which milk is heated to a temperature which is high enough to kill most

Gendreau

Fig. 384. This Modern Refrigeration Tank is like a Large Vacuum Bottle

Fleets of such trucks carry the supply of milk to large cities

of the bacteria but not high enough to injure the food value of the milk. In common practice it is heated to a temperature of 145° F. (62.8° C.) and held at this temperature for thirty minutes. Precautions have been taken to keep bacteria of tuberculosis, typhoid fever, diphtheria, and others from the milk, yet there is always danger when milk is handled by many people that some bacteria will get in. But if they do, they are killed by pasteurization. Some of the bacteria which cause milk to sour may be killed also. A count of 1,000,000 bacteria per cubic centimeter may be reduced to 10,000 per cubic centimeter by pasteurization. After the milk is pasteurized, it is poured by machinery into sterilized bottles, and the bottles are capped. You may gain some idea of the care taken to guarantee a pure milk supply by studying Fig. 385.

The question of the number of bacteria in milk is not so important as the question of what kinds are there. It is important to know that in milk that has been properly pasteurized there are no bacteria that can cause disease.

What is Grade A milk? There are two kinds: Grade A raw and Grade A pasteurized. The former may be sold

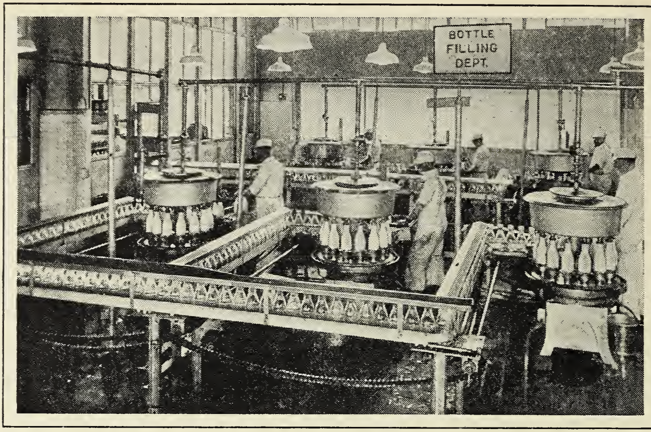


FIG. 385. The Processes by which Milk is prepared for the Market are carefully guarded against Dirt and Bacterial Infection

This picture shows the bottling department of a modern dairy

as certified milk, representing the highest standard. The cows producing such milk must be kept in sanitary barns, be regularly tested by a veterinary, and be certified free from tuberculosis. The dairy workers must undergo medical examination and be certified free from disease.

In common practice certified milk must have a count not above 10,000 bacteria per cubic centimeter when delivered. Milk containing more than 10,000 bacteria per cubic centimeter but less than 200,000 may be sold as Grade A milk only after it is pasteurized. At the time of delivery the pasteurized Grade A must not contain more than 10,000 bacteria per cubic centimeter. Grade B milk also is produced from cows that have been tested and found free from tuberculosis. The count of bacteria may run as high as 1,000,000 before pasteurization, but in common practice there must not be more than 50,000 bacteria per cubic centimeter at the time of delivery.

The grading of milk is based in part upon the count of bacteria in it

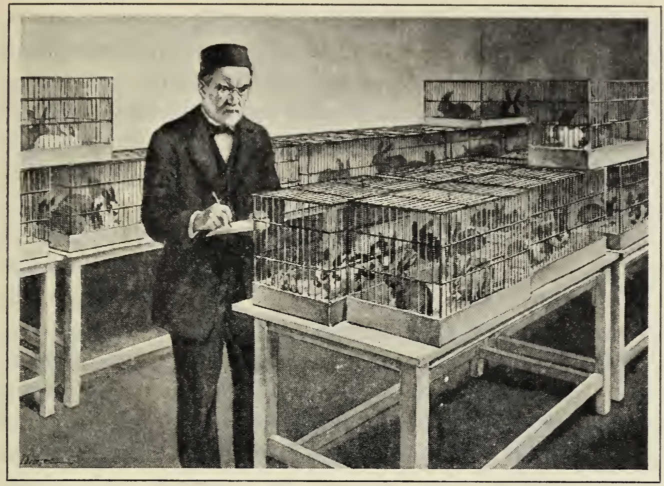


FIG. 386. LOUIS PASTEUR, *who discovered a Cause and Cure for Several Contagious Diseases (1822–1895)*

THE SON of a tanner in a little French village, Louis Pasteur went to school and college, and became a professor of physics and chemistry. Circumstances caused him to become interested in the fermentation of wines. He tried to find out why milk sours and why foods spoil. He found minute organisms, or living things, doing the damage, each kind of organism producing its own particular effect · Silkworm diseases claimed his attention while he was teaching in the south of France, and these too he found to be caused by organisms or germs which could be seen only with a microscope · The ability to keep at the things he started next led Pasteur into a study of anthrax, a disease contracted alike by animals and by man. This too was caused by a germ. And now he began to ask himself how to cure or prevent such diseases. This was a generation or more after vaccination had been tried and found successful. Pasteur forced into cattle mild doses of anthrax germs, gave them the disease lightly, then more strongly, and they became immune without ever having been sick. He followed the same methods in treating chickens with the germs of chicken cholera. Then came hydrophobia, or rabies. This is a disease, nearly always fatal, contracted from the bite of a mad dog. Could this terrible disease be treated in a similar manner? Preliminary experiments had suggested the way. The opportunity came to save a small boy's life. His method worked. Philanthropists established a place in Paris in which Pasteur could carry on his work and take care of all the patients who came to him.

It is extremely important that milk production be carefully controlled. There is very good evidence that epidemics of typhoid fever and of diphtheria have been caused by milk. Such epidemics may still break out in regions where pasteurized milk is not used, but such outbreaks caused by milk are hardly possible in cities where pasteurized milk is used.

As you can see, sanitary standards for milk in America are high. Wherever you may go, you may find in large cities pasteurized milk for sale. This you may drink without fear of disease, in striking contrast with what you may safely do in many, if not most, foreign countries. There are indeed but few places in the world outside the United States where a traveler may feel safe to drink raw milk with his meals. If he uses it at all, he takes only milk that has been boiled. In England, for example, only about 20,000 cows were used in the production of graded milk in 1927. At about the same time there were in the United States more than 2,000,000 cows used in the production of graded milk. All of them had been tested and found free from tuberculosis. Perhaps some figures will bring out the importance of these facts. Only Switzerland and Sweden use more milk per day per person than we do in the United States. England, France, and Germany use much less. For comparison, Switzerland uses 1.83 pints per person per day. In the United States we use 1 pint. In England the quantity is 0.44 pint.

B. What may be done with Garbage?

Great quantities of useless material collect every day in a city, and a large part of this material is made up of the wastes from the handling and preparation of foods. You find fruit peelings and seeds, pods of peas and beans, nutshells, waste leaves from green vegetables, spoiled foods, and many other things.

The waste materials in garbage are chiefly organic matter, a term used to include all the products of plant or animal origin. Since this is so, almost everything in garbage is food for bacteria and other fungi. Much of it is food for rats and mice and for flies and other insects in great variety. Then, too, birds and larger animals, including skunks, muskrats, and others, secure some of their food from refuse. In Yellowstone Park, for example, a chief source of food for the big brown bears so numerous there is the garbage from the park hotels.

You may have seen garbage dumps on the outskirts of a large city. What becomes of them? As the organic matter is used for food by the animals, by bacteria, by molds, and by other forms of life, it is changed to the chemical elements of which it is composed. Carbohydrates and fats are, as you know, composed of carbon, hydrogen, and oxygen. Proteins contain these same elements, together with nitrogen, sulfur, and small amounts of some other elements. The mineral salts are compounds containing calcium, phosphorus, sodium, potassium, and some other elements.

Garbage decays through action of bacteria and other fungi

Ordinarily you would say that garbage decays. But the decay is only the change that takes place as organisms feed upon the garbage. You know how foods are used in the cells of your own bodies. Energy is released from the foods as they combine with oxygen. In the chemical change which occurs the carbohydrates and fats are changed to carbon dioxide and water. Proteins are reduced to these same simple compounds and to simple compounds of nitrogen, of sulfur, and of a few other elements. These leave the body by way of the lungs and the kidneys. The chemical changes in decay are about the same as the changes that take place while energy is being released in the cells of your body.

Bacteria and molds are the chief agents of decay. In the garbage heap, where there is plenty of food for them, they

multiply to enormous numbers. They are living things requiring food for energy and for growth. Each organism digests, in much the same manner as food is digested in your body, the food on which it grows. The garbage is changed to a soluble form. In every cell there is a flow of dissolved food, and from every cell there is a flow of gaseous compounds that escape into the air. In the process of decay garbage is changed into simple substances, mostly carbon dioxide and water, and a small amount of mineral compounds.

Why does decaying garbage produce a disagreeable odor? Both carbon dioxide and water are odorless. But proteins, you will remember, contain the elements nitrogen and sulfur. As proteins decay, compounds of these elements are released as gases, and they cause the odors. You are familiar with the odor of ammonia (NH_3). You may recognize its odor in the gases released from a garbage heap. You may be familiar with the foul-smelling gas known as hydrogen sulfide (H_2S). It also is released as a product from decay. A mixture of these compounds, together with other compounds of these same elements, cause the familiar but disagreeable odors of decay.

The odors of garbage are caused by chemical substances released by action of bacteria

The garbage heap is an extremely objectionable feature of the environment. We don't like the odors that come from it. But probably of more importance than the disagreeable odors is the fact that it serves as a source of food and as a breeding place for pests. Among the pests that breed in decaying garbage, flies and rats are the most objectionable.

You may know the life cycle of the house fly. Eggs are laid on partly decayed matter, which serves as food for the larvæ. In warm weather the interval from egg to adult fly is about twenty days. Since a single fly may lay more than a hundred eggs at one time, you may expect that during warm weather there will be a swarm of young flies

rising continually from the heap of decaying garbage. You know, too, that flies are dangerous carriers of disease.

You don't need to stay about a garbage heap very long to learn that it is infested with rats. These too develop at an enormously rapid rate when there is plenty of food. One female rat will produce young as often as four or five times in a year, and in each litter there will be from four to ten young. At the age of about six months the young ones will be old enough to produce more young ones. If there were ten rats in each litter, how many would there be from one pair of rats by the end of one year? You may get the answer from a simple calculation. Provided that there was sufficient food and that none of the rats died, one pair of rats would at the end of one year have been responsible for ninety-five pair, or a hundred and ninety individuals. How many would there be at the end of the second year? The number would be enormous. Almost as many, it would seem, as followed the Pied Piper of Hamelin. Of course, rats do not really reproduce as fast as this, for there would not be food enough for such a large number. These figures show the greatest number that might be produced under most favorable conditions. There will be none if there is no food for them. Since rats flourish on garbage, it must not be left in dump heaps. What may be done with it?

Many forms of animal life live and flourish on garbage

As do flies, the rats present a definite danger to health. It is believed that the dreaded plague which swept Europe in the fourteenth century and which you may have heard of as the Black Death is carried by rats. All countries have taken strict measures to protect their people from the spread of this horrible disease. Not only are rats a menace to health, but they are an economic problem, as you may have realized if you have ever seen the damage these animals do to corn and other grains stored in granaries.

The problem of getting rid of garbage, then, is an important one. What shall be done with it? Some communi-

Ewing Galloway

Fig. 387. In Many Cities Garbage and Other Refuse is dumped, forming Unsightly Piles like This

Do you think such a method of disposal is very sanitary?

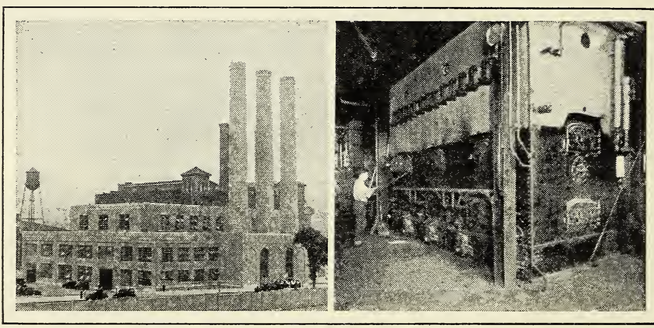


Fig. 388. The Most Effective Way to get rid of Garbage is to burn It

More and more cities are erecting incinerators similar to this one

ties still have dumps, as shown in Fig. 387. Are these an aid to sanitation? Other cities collect their garbage, load it on flat-bottomed boats, and dump it far out at sea.

Even this is no solution, for the wind and waves carry some of it to near-by bathing beaches. The simplest way to get rid of garbage is to burn it. In an incinerator, like the one in Fig. 388, garbage is burned at a high temperature (about 900° C.). The carbon, hydrogen oxygen, and nitrogen of which foods are composed become parts of gaseous compounds and escape into the air. There are no objectionable odors from an incinerator, for at this high temperature none of the foul-smelling gases of decay are produced. Within a few minutes after the mussiest and filthiest garbage is placed in an incinerator, there is nothing left of it but some clean white ashes.

The most effective way to get rid of garbage is to burn it

Community health and comfort require that garbage be disposed of in such a manner that it does not serve as a breeding place for flies, rats, and other community pests.

C. What may be done with Sewage?

Sewage carries the wastes from the human body and may therefore carry all the kinds of disease germs that are known to the human race. As with garbage, the problem of getting rid of sewage is important to human health.

An application of simple scientific principles helps to solve this problem. Consider first the chemical composition of the waste products.

They are composed chiefly of the same chemical elements that are found in food, namely, carbon, hydrogen, oxygen, and nitrogen, together with small amounts of sulfur, phosphorus, and some other elements. These wastes, like garbage, serve as food for bacteria and some other forms of life. The bacteria change the wastes into carbon dioxide, water, and ammonia, with very small amounts of some other substances. In getting rid of sewage, conditions should be made favorable for these bacteria to live and grow, for as they grow they destroy the sewage.

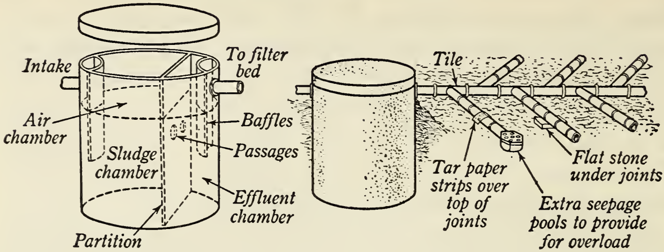


Fig. 389. A Simple Septic Tank is an Effective Means of Disposing of the Sewage from a Single Home

Do you understand how the sewage is destroyed?

The action of bacteria upon sewage aids in destroying it

Cities located along streams commonly discharge sewage into the river. This practice may be permitted, provided there is a large flow of water and provided there are no near-by cities downstream. What happens to sewage after it flows into a stream? The bacteria normally found in the water feed upon it. When there is only a little sewage for a large amount of water, the sewage is soon completely destroyed. It is interesting to observe that cities along the Mississippi River and its tributaries dump sewage into the river; yet the water is nearly free from evidence of sewage when the great river flows into the Gulf of Mexico.

What becomes of the disease germs in the sewage? They are adapted to live at the temperature of the human body. Therefore they do not flourish outside the human body.

The bacteria of typhoid fever likely to be present in sewage may live for a time. They feed upon the waste matter that is carried in the water. But as this is destroyed, the typhoid bacteria die. If the water is heavily loaded with sewage, however, disease germs will live longer in it than if the water contains but little sewage. In thickly settled regions, therefore, where towns are close together,

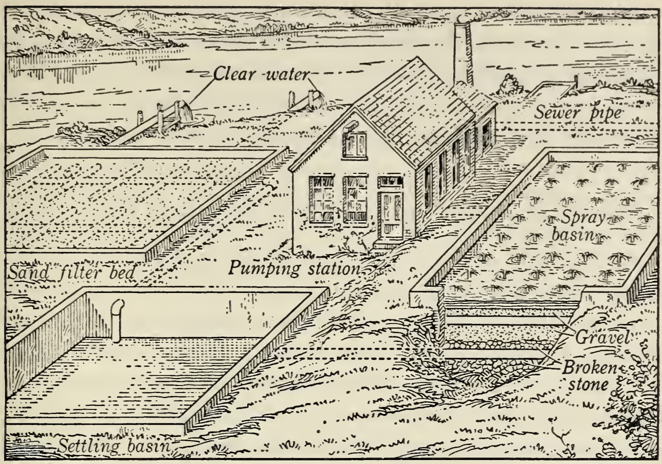


FIG. 390. Many Large Cities handle their Sewage through Disposal Plants Similar to this One

How does such a plant provide conditions favorable for the action of bacteria?

the practice of dumping sewage into a stream is very objectionable and dangerous to health.

Modern methods of getting rid of sewage attempt to provide conditions favorable for action of bacteria

There are other possible ways of getting rid of sewage. The sewage from a residence may be effectively taken care of through a septic tank, as diagramed in Fig. 389. This system, while it may seem complex, is simply a means to provide conditions favorable for the work of bacteria. As the sewage is held in the tank, it is changed into liquid and gaseous matter. There is an overflow pipe near the top of the tank. Through it the liquid flows out and seeps away in the surrounding soil.

Many large cities take care of their wastes through special plants. In their common form these plants are composed of a number of large septic tanks, as shown in Fig. 390. Without question this is a far more satisfactory

way in which to get rid of sewage than to dump it into near-by streams. Regardless of the plan used, however, the modern methods for getting rid of sewage attempt to make conditions favorable for the growth of those bacteria which feed upon and destroy the waste products in sewage.

D. How may we get an Abundant Supply of Pure Water?

As a result of your previous work in science you may know quite a little about the means by which man today provides himself with a sufficiently large supply of pure water. You may even have made a rather careful study of your local sources. This section of the unit will not repeat the principles you have already learned, but will show how communities try to make sure of a safe supply.

What are the possible dangerous conditions in water against which we must guard? The water which flows in city mains is commonly pumped from rivers and lakes. An examination of such water would show that it contains mineral salts which have been dissolved from the soil as the stream flowed along. It would also contain some sediment, which would make it appear more or less muddy. There would certainly be some bacteria in it; and if waste products from the body of a person suffering from typhoid fever were allowed to flow into the stream, it would probably contain bacteria that would cause this illness. River water ordinarily has some odor, caused by the decay of organic matter carried in the water. A satisfactory water supply, however, is free from sediment, dangerous bacteria, and odors.

What has been done to guarantee a satisfactory supply? The sediment may be removed by a chemical process of sedimentation and by filtering through sand. Or it may be removed by simply allowing time for the tiny particles to settle. If water is quite muddy, like water taken from the Mississippi River, it is treated by the chemical process

and filtered through sand. If there is but little sediment in the water, as is the case with water taken from the Catskill Mountains for use in New York City, neither a chemical process nor sand filtration is necessary.

Most of the bacteria also will be filtered out if the water is filtered through sand. As stated before, bacteria which produce disease are adapted to live in the human body. Outside the body they are easily killed. In the pasteurization of milk they are killed by heat, while other bacteria (harmless ones) are not killed. In the purification of water they are killed by the use of chlorine. Scientists who have made a special study of bacteria continually guard the water supply and at regular intervals make counts of the number of bacteria in a measured sample. When the count runs high, more chlorine is used; and when the count is low, less of it is used. Chlorine may be used in sufficient quantity to be tasted, but even in this concentration it is entirely harmless to those who drink the water.

Modern sanitation is a matter of strict control

This study of foods, of methods of taking care of garbage and sewage, and of water supply is sufficient to illustrate the importance of measures for maintaining community health. There was a time when the relations between sanitation and health were unknown. Epidemics of disease, including bubonic plague, cholera, malaria, yellow fever, typhoid fever, and others, might break out with great loss of life, and no one would know why they broke out nor how to control them. Not long ago people generally believed that outbreaks of these diseases were the work of the devil. Even today it is not uncommon to find people who lay the blame for their ills on broken mirrors and black cats and seek protection in a rabbit's foot or a horseshoe. But today the causes of all these illnesses are well known and so effectively under control that cases are extremely rare. If a case of typhoid, for example, were to break out in an American city today, it would probably come either from

milk or from water. It might come from some other source. But in any case the board of health could probably trace the case to the cause that produced it, and the board would probably be able to place personal responsibility on the individual whose negligence allowed the case of illness to develop. The only explanation that can be offered today for the development of typhoid fever is negligence. Man has made great progress in his efforts to control the causes of illness in the community.

Community sanitation demands constant alertness on the part of the individual, as well as of the agencies he has set up to aid him. Such factors as pure food, satisfactory water supply, and methods of disposing of garbage and sewage must be carefully controlled if sanitary conditions are to be maintained in the community. This control depends to a great extent upon common principles of science.

Can You Answer these Questions?

1. What is meant by *pasteurization of milk*? Why is the process used?

2. How does Grade A milk differ from Grade B milk?

3. In what ways are house flies not only objectionable but really dangerous?

4. What are some of the standards by which one can measure how well a community protects the health of its population?

5. How does canning help to preserve foods?

6. What causes milk to turn sour?

7. Why does decaying garbage produce a disagreeable odor? Why is careless garbage disposal a menace to the community?

8. What are some common ways in which communities handle the problem of sewage disposal?

9. What are some of the steps taken to guarantee a pure water supply?

Questions for Discussion

1. What is meant by *loose milk*, and why is its sale a menace to health?

2. How are garbage and sewage disposed of in your community?

3. Suppose you wanted to become a bacteriologist. What courses should you take in college?

4. Why is each of the standards suggested on page 629 for the measurement of community health important?

5. What does your community do to secure a pure water supply?

6. Is public health more important in the city or in the country?

7. Why should milk, which is almost 90 per cent water, be considered such a valuable food?

Here are Some Things You May Want to Do

1. Make a study of your local community to find out how its health is protected. What health officials are there, and what are their duties? Are there any conditions which are dangerous to community health? How may they be corrected?

2. Do you think our present laws are sufficient to protect community health? Discuss this question after you read *One Hundred Million Guinea Pigs.*

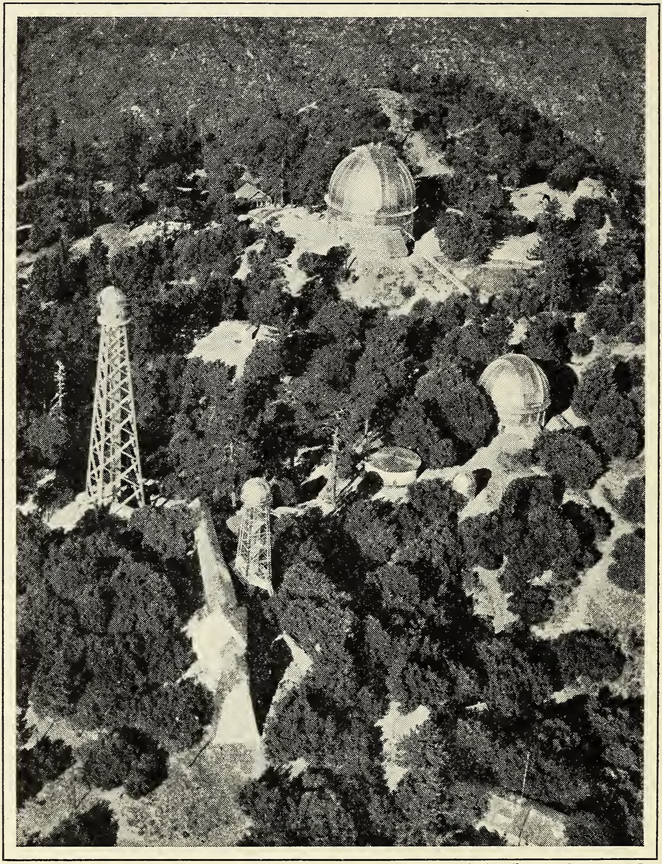
3. Look over the foods in your kitchen at home and see if you can find some of the ways in which they have been protected against dirt and bacteria before they reached you.

4. Visit a dairy or a milk-bottling plant to find out how milk is prepared for use. If a visit is not possible, perhaps you can get a motion-picture film which will give you this information.

5. If you can get some fresh milk, pasteurize a small part of it. How could you find out what changes took place?

6. If you have a public-health officer in your community, ask him to speak to your class on the ways in which foods are tested for impurities and adulteration.

7. One of the outstanding men in the fight for pure-food laws was Dr. Harvey W. Wiley. Find out about him and write a short account of his life and work.

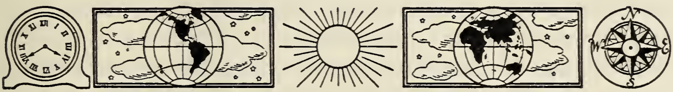


Fairchild Aërial Surveys, Inc.

Fig. 391. The Work carried on in Modern Observatories such as this one on the Top of Mt. Wilson in California has greatly increased Man's Knowledge of Outer Space

UNIT VII

How has Man learned about the Position in Space of the Earth and Other Bodies?



Chapter XXIX · How has Man measured the Earth and determined its Position?

Chapter XXX · What is the Nature of Light, and What may be learned through the Use of Optical Instruments?

Chapter XXXI · How have New and Better Tools extended our Information about the Universe?

Chapter XXXII · What is the Origin of the Solar System, and What lies in Space beyond It?

THERE is abundant evidence that men have always asked themselves as they looked at the skies, What is up there? We are poorly equipped by nature to answer this question. With our eyes we see points of light which seem to be always in the same relative positions to each other. These are the stars. We see other bodies that are continually moving, for their position in relation to each other and in relation to the stars changes from day to day. These are the planets.

As we read of the achievements of ancient people in the study of the heavenly bodies, we are much impressed, for they had no instruments with which to extend their range of vision. There were, though, definite limits to what they could do. No man with an unaided eye could distinguish the mountains on the moon, see the satellites of Mars and Jupiter, notice the rotation of these planets, or follow through the phases of Venus.

When Galileo made his telescope and turned it on the sky, a new world of discovery was opened. The eager search for knowledge was richly rewarded and new discoveries led men to seek for more and more. The eagerness of this search is illustrated by accomplishments in making telescopes. Man is unable to control and use the stars and the planets, but through exercise of his intellect he has been able to control and use the energy of light beams and make them furnish for him at least a partial answer to the question, What is up there? The story of these achievements is told in this Unit.

Chapter XXIX · How has Man measured the Earth and determined its Position?

A. What were the Ideas of Leading Greek Thinkers about the Universe?

You may have thought that Columbus was the first man to believe the earth round, or that all men before Copernicus thought the earth to be the center of the universe. But this is not true, for there were among the ancient Greeks, and probably in other civilizations such as the Chinese and Mayan, certain able men who had surprisingly modern theories about the earth and the sky. Let us study some of these early notions.

The Greeks had suggested the main features of the Copernican theory some five hundred years before Christ

Thales of Miletus (640–546 B.C.) predicted the eclipse of the sun which came in 585 B.C. He must have known something about the earth's motions. Pythagoras, famous for his work in mathematics, taught during the sixth century B.C. that the earth is round, and gave as proof the curved shadow of the earth seen on the moon during an eclipse. Some of his pupils, in fact, taught that the earth moves around the sun. During the fourth century B.C. another Greek philosopher (Heracleides Ponticus) stated that the apparent daily motion of the sun and the stars is due to the rotation of the earth on its axis and not, as was generally believed at that time, to the motion of these bodies around the earth.

One of the great difficulties in the way of accepting these theories was the observation that the stars seem to remain throughout the year in the same relative positions. No one imagined then, of course, that even the nearest of the stars are so far away that the earth can travel once a year around the sun and appear to be as near a given star on one side of its orbit as on the other.

Aristarchus of Samos (third century B.C.) was one of the first to measure distances in space. He guessed that the sun is bigger and farther from us than the moon, reasoning somewhat as follows: When the moon is exactly at first quarter or last quarter, so that we see half of its lighted surface, then the earth, moon, and sun form a right angle (as shown in Fig. 392, *A*). This, you will see, is correct. He could measure the angle indicated by the arrow, by sighting along a line to the moon and by sighting at the same time along a second line to the sun. He measured this angle as 87 degrees. He then drew a triangle like the one in Fig. 392, *A*, and by careful measurement showed that the line representing the distance from the earth to the sun was twenty times longer than the line representing the distance from the earth to the moon. Of course you see that his answer was far from correct, for measurements have shown that the distance from the earth to the sun is nearly four hundred times greater than the distance from the earth to the moon. But his method was correct. His error was in the measurement of the angle. The true value is 89.84 degrees, and the value obtained by Aristarchus was 87 degrees.

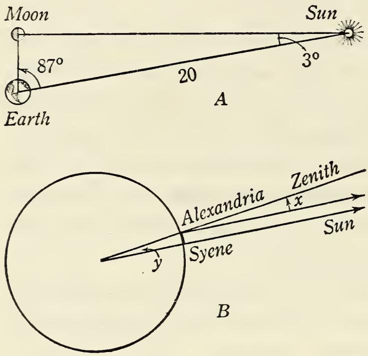


FIG. 392. Some of the Methods used by Ancient Peoples to find out about the Relationships of the Heavenly Bodies were Quite Accurate

At the top is shown how Aristarchus proved that the sun is more distant than the moon; at the bottom is shown how Eratosthenes measured accurately the circumference of the earth

Aristarchus proved that the sun is more distant than the moon

About the time that Aristarchus was attempting to figure

the distances to the moon and the sun, Eratosthenes, a Greek who lived in the city of Alexandria in Egypt, drew up a plan for measuring the circumference of the earth itself. Let us show you how he did it.

About 500 miles south of Alexandria was the city of Syene; and since this was located well within the torrid zone, the sun at noon at certain times of the year was directly overhead. At the same time in Alexandria, however, the sun was not overhead (as shown in Fig. 392, B). There was an angle (x) between a line to the sun and a line to overhead (the zenith). Now you may see, as Eratosthenes did, that this angle x is of the same size as angle y at the center of the earth. "Very well, then," reasoned Eratosthenes, "we shall measure angle x. Then we shall measure very carefully the distance from here to Syene. The angle x will be the same part of a circle (360 degrees) as the distance between the two cities is of the circumference of the earth."

Eratosthenes measured accurately the circumference of the earth

The angle was found to be 7 degrees 12 minutes. This is exactly one fiftieth of a circle. The distance between the two cities was 500 miles. Therefore the distance around the earth was 50×500 miles, or 25,000 miles. This answer is very nearly correct.

But these ancient Greeks had to be content to know such things for themselves. They had no elaborate systems of broadcasting new discoveries to the world — no radio, no newspapers, no printing press. Only the rich could read and write. Philosophers — some of them — believed that the earth was round and that it revolved about the sun. Most people knew nothing of the world beyond their own fields, nor did they very much care.

But few people were educated in ancient times, and most people knew nothing of astronomy

True, there was a great library at Alexandria in the days of Eratosthenes, as there had been earlier at Athens. The star maps in those days were accurate and are used for

reference even today. To be sure, the men who collected information and the manuscript-writers failed to accept the theory of Aristarchus that the sun is at the center of the solar system. Indeed, we should never have known about it if Archimedes, in Sicily, had not happened to quote the theory in order to deny it.

B. How does Modern Man find his way about the Earth? What are Latitude and Longitude?

We have told you how Eratosthenes measured the earth's circumference, and we have referred to his other measurements of latitude. The Phœnicians too and other early sailors were eager to determine their positions and their direction from home when out upon unknown waters. They found the sun and stars useful for this purpose, and they too became expert at measuring angles. Accurate determinations of latitude and longitude resulted.

Sailors need a scheme for "finding" themselves when far from land

This scheme has been worked out as a definite result of increased knowledge concerning the shape and motions of the earth. *Latitude* and *longitude.* What do these words mean? They both come from the Latin, one from a word meaning "broad" and the other from a word meaning "long."

In your mathematics classes, as well as earlier in this chapter, you have already measured circles and know that a circle is equal to 360 degrees. A half-circle, then, is 180 degrees, and a quarter-circle is 90 degrees. Since the earth is a sphere, any part of the distance around it, measured in any way, is really distance measured around some part of a circle. Fig. 393 will illustrate this. If you travel from point A to point B or from B to C or from A to C, you are traveling along a circle.

Distance around the earth is distance around a circle

The fact that distance traveled on the surface of the earth is really distance on a circular line forms the basis

for determining latitude and longitude. Imagine two circles drawn around the surface of the earth. One extends from east to west around the earth halfway between the poles and is called the equator. Imagine the other circle extending north and south through the poles.

Now let us see how we can measure distances north and south. Remember that *north* always means toward the north pole, and *south* means toward the south pole. The equator is, as you know, a great circle around the earth just halfway between the north pole and the south pole. Any point on the equator is said to be at 0 degree latitude; points north of the equator are in north latitude, and points south of the equator are in south latitude. Since a line drawn from the equator to either pole would be a quarter-circle, there are 90 degrees of latitude between the equator and either pole.

FIG. 393. Distance around the Earth is Distance around a Circle

The north pole, then, is located at 90 degrees north latitude, and the south pole is located at 90 degrees south latitude. If you will look at a map of the world, you will see drawn around the earth a line marking the position of the equator. This, you will notice, is 0 degree latitude. Paralleling the equator, other lines are drawn north and south of it. Just as any point on the equator is at 0 degree latitude, so any point on the line located 10 degrees north of the equator is at 10 degrees north latitude, whether it is in Africa, Central America, or elsewhere.

Latitude indicates distance north and south of the equator

Notice that similar lines, or parallels of latitude, are drawn at intervals on both sides of the equator.

Longitude indicates distance east and west of the Greenwich meridian

Meridians of longitude are used for determining distances and directions east and west. To represent longitude, meridians are drawn from pole to pole, cutting the parallels at right angles. Since there is no definite point such as the equator to use as 0 degree longitude, one had to be selected. Today all countries use as the 0 degree meridian the one that runs through Greenwich, England, the home of the British National Observatory. Longitude is measured from 0 degree to 180 degrees eastward and from 0 degree to 180 degrees westward. The 180th meridian is not called either east or west, but merely the 180th meridian.

Fig. 394. Latitude indicates Distance North and South of the Equator; Longitude indicates Distance East and West of Greenwich

With this system you can locate any point exactly. For example, you can indicate a place as being at 45 degrees north latitude and 76 degrees east longitude. Immediately anyone understanding the system can locate very definitely that place on the map.

By looking at the map you may learn the latitude and longitude of places on the surface of the earth. The distance from the equator to the poles is one fourth the distance around the earth. It is therefore 90 degrees. Minneapolis, Minnesota, is at 45 degrees north latitude. Minneapolis is just halfway between the equator and the north pole. Cen-

tral Patagonia, in Argentina, South America, is at 45 degrees south latitude. Central Patagonia is therefore halfway between the equator and the south pole.

St. Louis, Missouri, is at 90 degrees west longitude. The distance from the meridian that passes through Greenwich to the meridian that passes through St. Louis is therefore just one fourth of the distance around the earth. The meridian of 90 degrees east longitude passes through the plains of Tibet in Asia and near Mount Everest. Mount Everest is therefore just halfway around the earth from St. Louis. A traveler could travel from St. Louis toward Mount Everest by going either east or west, and in either case the distance would be the same.

C. Where do we get our Scheme for Telling Time?

Some of you may have listened to radio broadcasts from England. You may have heard the king at six o'clock in the morning. If so, perhaps you, like others, wondered why he should get up as early as that to make a speech. Strange to say, however, when it is six o'clock in the morning in New York, Boston, or Philadelphia, it is eleven o'clock in the morning in England. After all, that is not so early for speech-making.

Time differs at different places

Perhaps you have listened to broadcasts of football games between rival Eastern colleges. When the games are over at about half-past five in the East, those of you living on the eastern coast of the United States may have turned the dials to the beginning of a broadcast of a game between colleges on the western coast. Many times you sit under electric lights in the East and listen to a description of a game being played in brilliant sunshine on the Pacific coast. Similarly those of you who live in the Far West listen before and during lunch to broadcasts of Harvard, Yale, Princeton, and other Eastern games.

How may these common experiences be explained? Will your knowledge of latitude and longitude help? Is there any relationship between them and the shape and motions of the earth? Let us see.

The earth, you learned, turns on an axis. This rotation proceeds at a uniform rate; and, so far as is known, there is no force acting to stop it or to make it move faster. The time required for one rotation of the earth may be measured by the interval of time between the instant the sun is directly over a meridian and the instant it is next over the same meridian. This length of time is one solar day.

It is noon on a meridian when the sun is over it

It is noon on a meridian at the instant the sun is directly over that meridian. Obviously, then, it cannot be noon at the same instant at different positions on the same east-and-west line, or parallel of latitude. It is noon at the same time, however, at all positions on the same meridian of longitude. The position of noon, then, moves from east to west as the earth turns from west to east.

Since there are twenty-four hours in one day, the earth makes one twenty-fourth of a complete turn in an hour.

A point on the earth rotates through 15 degrees in an hour

When it is noon at one place, it must be one hour before noon at a position 15 degrees farther west. Why fifteen? Since there are 360 degrees in a circle, you will see that during every hour every point on the earth turns through 15 degrees of longitude ($360 \div 24 = 15$).

Consider now the difference in location of various points and their relation to the sun at a particular time. Philadelphia is at 75 degrees west longitude, St. Louis is at 90 degrees west longitude, Denver is at 105 degrees west longitude, and Yosemite National Park is at 120 degrees west longitude. When it is noon in Philadelphia, it is one hour before noon in St. Louis, two hours before noon in Denver, and three hours before noon in Yosemite National Park. One hour after the vertical rays of the sun are over

FIG. 395. The Shape and the Rotation of the Earth determine our Time Scheme

Notice that for every fifteen degrees of longitude there is a change of one hour in time

the meridian that passes through Philadelphia they will be over the meridian that passes through St. Louis, for in this interval the earth will have turned through 15 degrees. If you will look at a map or a globe (Fig. 395), you find that when it is noon in Philadelphia it is midnight over the plains of central and southern China.

Here, it would seem, is a good basis for a time scheme. Why not use solar time as a unit of measurement? The sun would be a kind of universal clock. The question

"What time is it?" could be answered with "Why not look at the sun?" As you study these questions a little, however, you begin to see that solar time would cause a great deal of inconvenience. Noon to one person would not be noon to another person living east or west from that person. You may think of noon as approaching from the east as the earth turns and leaving toward the west. If a person said, "I will see you at noon," he would have to say whether he meant noon according to his solar time or the solar time at the point where his friend lived. If a railroad used solar time, it would have to indicate whether the time of arrival of trains at a certain point was local solar time or not. With this plan, then, no two places would have the same time unless they were located on the same meridian.

Solar time is not convenient for ordinary use

In 1864 an international congress was held in Washington for the purpose of arriving at some definite universal time plan. At this congress it was agreed that the meridian of 0 degree, at Greenwich, England, should be the standard time meridian. Further, it was decided that a number of time belts should be set up and that within each of these belts the same time should be in effect. How should these belts be determined? This was very simple. You know, as did the members of the congress, that the earth turns through 15 degrees of longitude each hour and that there are twenty-four hours in a day. Since this is so, they said, let us place the boundaries of the time belts 15 degrees apart.

Time is now arranged by time belts

When it is noon at Greenwich at 0 degree longitude, all accurate watches within the 15-degree zone, or belt of longitude, which has Greenwich as the center indicate noon. Another time belt has its center at 15 degrees west longitude, another at 30 degrees west longitude, still another at 45 degrees longitude, and so on around the earth.

Time belts are 15 degrees wide

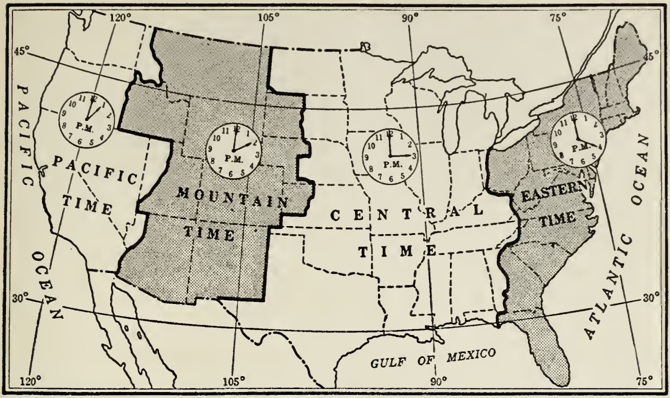


FIG. 396. There are Four Time Belts in the United States

In the United States there are four time belts. They determine what is called Eastern time, Central time, Mountain time, and Pacific time. Each belt is about 15 degrees wide. These time belts are indicated in Fig. 396. The boundaries of the belts are not straight. Can you guess why this should be so? Consider a city located directly on a boundary meridian. Would it be very convenient if one side of the town had Central time, while the other side had time an hour later or earlier? Let us see how these time belts are used. When the traveler goes from one time belt to the next, he must change his watch by one hour; for when it is three o'clock in the Central time belt, it is two o'clock in the Mountain time belt. As he travels from east to west, he must set his watch back one hour as he moves from one time belt to the next. As he travels from west to east, he must set his watch forward as he moves from one time belt to the next. See if you can find a railroad time-table which shows how time changes.

There are four time belts in the United States

The time kept by ordinary clocks and watches is standard time. There is in each time belt one meridian on which

standard time and solar time are the same. In the Eastern time belt this meridian is the one that passes through Philadelphia. At the eastern edge of a time belt the solar time is about thirty minutes ahead of standard time, and at the western edge of the belt the solar time is about thirty minutes behind standard time. In other words, if you live on the edge of a time belt, the sun is not directly over the meridian where you live when the clocks in your city indicate noon. Standard time may be thought of as the average solar time of the time belt.

Standard time is average solar time

At the latitude of Washington, D.C., a spot on the surface of the earth is carried forward, as the earth turns, at a speed of about 800 miles per hour. If a person had an airplane capable of this speed, he could start westward at noon and continue his travels all the way around the earth with the sun all the time in the position of noon. If he traveled eastward at this speed, he would, if he started at noon, arrive in just twelve hours at a position in which it would again be noon. In another twelve hours he would be back at his starting place, and it would be noon again. What does this mean, practically? A traveler going westward must set his watch backward every time he crosses a time belt. If he continues around the world, traveling westward, he will set his watch backward twenty-four hours, or one full day, during the journey. In this way he would seem to lose a day; but when he returned to his starting place on what would seem to him to be Monday, he would find it was really Tuesday and he would not have lost the day after all. The International Date Line has been established in order to set this right. This line just about corresponds to the 180th meridian (Fig. 397). When a traveler crosses the Date Line, he changes time by one full day. If it is Monday on the east side of the line, it is Tuesday on the west side of the line. Thus when the traveler gets back to his starting place, his calendar will be correct.

The 180th meridian is the International Date Line

FIG. 397. The 180th Meridian is the International Date Line

Why does not this line run directly north and south?

When this time scheme was first placed in universal practice, some amusing difficulties arose. Did you ever read *Round the World in Eighty Days*, by Jules Verne? The plot of the story hinges upon a day which is "gained" in traveling around the world from west to east. A modern explorer, Dr. Harold McCracken tells in his book *God's Frozen Children* about two little islands lying between Alaska and Siberia. The longitude of Little Diomede Island, about one square mile in area, is measured west from

Greenwich. Two miles to the west lies Big Diomede Island, the longitude of which is east from Greenwich. The International Date Line passes between these two islands. When it is Monday on Little Diomede, it is Tuesday on Big Diomede. If you should walk across the ice from the bigger island to the smaller in midwinter, starting on Tuesday, you would arrive on Monday, thus "gaining" a day. As you travel back, you "lose" it again. Similarly, when you travel from San Francisco to China, you "lose" a day in mid-ocean; but when you return, you repeat a calendar day and thus regain it.

You should now understand how the length of a day, a week, a month, or a year is determined.

There are different ways to define a day

A day is defined as the length of time required for one complete rotation of the earth. This may be measured by using the sun as a point of reference. A solar day is the interval between the time when the sun is directly over a meridian and the time when it is again directly over the same meridian. Sometimes astronomers use some other star instead of the sun. In that case they speak of sidereal days, or star days, instead of solar days. There are still other kinds of days used for special types of scientific work.

A lunar month, about twenty-nine and a half days, is the interval from one full moon to the next. All the changes in the moon from one full moon until the next are completed 12.4 times in one year. The interval between one full moon and the next full moon is divided into four phases, or stages. The week is an interval that corresponds closely to one of the moon's phases.

The year, like the day, is a natural unit of time. It is the time required for the earth to make one revolution around the sun. The length of the year has been measured very carefully. It is about three hundred sixty-five and a fourth days. More accurately, it is 365 days, 5 hours, 48 minutes, and 46.98 seconds.

D. Why do we need an Accurate Calendar?

The first calendar similar to the one we use today was made in 46 B.C., during the time of Julius Cæsar, and it is said that Cæsar got the idea from the Egyptians while he was visiting Cleopatra in Alexandria. It was called the Julian calendar. It was not, of course, the first calendar. Many people, including the ancient Greeks, Egyptians, Mayas, and Babylonians, had calendars. Theirs were based on the phases of the moon, however, while the Julian calendar was based on the earth's revolutions. In the Julian calendar the year was divided into twelve months of about equal length. After a slight change made by Augustus Cæsar, who followed his uncle, the Julian calendar as finally set up consisted of twelve months. Seven months had thirty-one days; four months, thirty days; and one month twenty-eight days. This is a total of three hundred and sixty-five days. Since the year is really about three hundred sixty-five and a fourth days, one day was added to the calendar every fourth year.

The calendar was once based on the motions of the moon; now it is based on the revolution of the earth

Since the year is not quite as long as three hundred sixty-five and a fourth days, there was an error in the Julian calendar. The year is really about eleven minutes and fourteen seconds, or seventy-eight ten-thousandths of a day, less than three hundred sixty-five and a fourth days. The year of the Julian calendar, then, was too long by this amount. In a hundred years this error amounted to about three fourths of a day; and in four hundred years, to three days. As the centuries passed, it became evident that a correction must be made.

In 1582 Pope Gregory XIII reformed the Julian calendar. Since the change was made more than sixteen centuries after Julius Cæsar, the error of the calendar by that time had amounted to about ten days. The Pope announced that ten days should be dropped from the month of Oc-

tober, 1583, and that the fourth of the month should be followed immediately by the fifteenth. He also decided that years divisible by 100 should not be leap years unless they are also divisible by 400. As you can see if you care to figure it, this shortened the Julian calendar by three days in four hundred years. The calendar worked out by Pope Gregory is now called the Gregorian calendar and is the one that we use. There is a little error in it, but it amounts to only one day in thirty-two hundred years. Three hundred and fifty years have passed since Pope Gregory corrected the calendar. It will not need correction by as much as one day for twenty-nine and a half centuries.

We now use the Gregorian calendar

Men have had strange ideas about the earth's position in time and space. Yet modern theories were held in some cases by ancient philosophers, some of whom made very accurate measurements. Means of determining location, direction, and time have come from man's knowledge of the shape and motions of the earth. As his knowledge of natural phenomena has increased, these measurements have become more accurate.

Can You Answer these Questions?

1. What are latitude and longitude? How are they used to determine the location of points upon the earth?

2. How are the time belts of the world determined? What is standard time? What time belts are there in the United States? How does time differ in these belts?

3. What is the International Date Line? What is its importance in our time scheme today?

4. What is the scientific definition of each of the following units of time measurement?

Solar day   Lunar month   Year   Sidereal day   Week

5. What is the difference between the old Julian calendar and our present Gregorian calendar?

6. What arguments are there in favor of calendar reform?

7. Is it correct to say that any distance around the earth is distance around a circle? How should you defend your answer?

Questions for Discussion

1. Do you think that if the findings of Aristarchus or Eratosthenes had been common knowledge in their time, it would have had any effect upon people then?

2. It has been said that the basis of latitude is more exact than the basis of longitude. Can you see any reason for this statement?

3. If you were sailing from San Francisco to Tokyo, should you lose or gain a day when you crossed the International Date Line? Can you prove your answer?

4. What advantages are claimed for schemes for daylight-saving?

5. In some reference books Isaac Newton's birth year is given as 1642. In others it is given as 1643. Can you explain this difference?

Here are Some Things You May Want to Do

1. Find out how a navigator far from land determines his exact position.

2. Find out all you can on the subject of astronomy among the American Indians, the Arabians, the Syrians, the Mayans, or some other ancient people.

3. Read Verne's *Around the World in Eighty Days.* In what ways does it seem very much out of date to you today?

4. Make or obtain a protractor and with it make an instrument to measure the angle between any two distant objects.

5. If you want to know more about man's ways of telling time, see if your library has a copy of Brearley's *Time Telling through the Ages.* If you would be interested in clocks or watches, look up Milham's *Time and Timekeepers.*

6. Read in an encyclopedia about schemes for calendar reform. Is such a reform needed?

Chapter XXX · What is the Nature of Light, and What may be learned through the Use of Optical Instruments?

It may be interesting to consider for a moment what happens to make you see the starry sky on a clear night. On a dark night, if your eyes are good, you may see about a thousand stars. On a moonlit night you cannot see nearly so many.

Each visible star is a source of light. You see the star because radiant energy in the form of light comes to your eyes from the star and stimulates your optic nerve. The stars are like the sun. They are hot bodies, so hot that they radiate light. The planets and the moon are unlike the stars in this respect. They do not radiate light. They are dark objects that are made visible only when the light of the sun falls upon them.

As we gaze into the starry sky, we see only points of light. How far away are they? What is the nature of the bodies from which the light comes? How big are they? Are the points moving? Answers to these and to many other questions are carried to us in the beams of light coming through the vast distances of space.

A. What is a Beam of White Light, and What is a Beam of Colored Light?

You know something of the range in wave length of radiant energy. The range is upward in length from the short cosmic rays, at one extreme, which are as short as one trillionth of a meter, to the extremely long radio waves, which are at least as long as 352,000 meters. Of this total range the human eye is sensitive to only an extremely small part, namely, those ranging between about 0.0004

There is a great range in the wave length of radiant energy

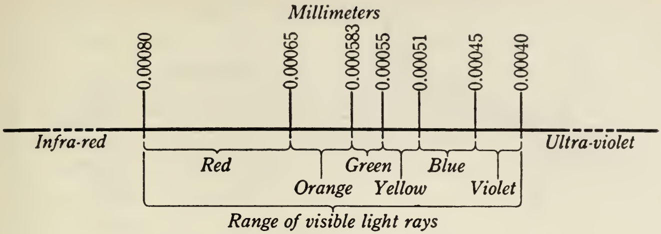


Fig. 398. The Waves of Visible Light differ in Length

millimeter and about 0.0008 millimeter. These are light waves. The longest waves of visible light are about twice as long as the shortest waves of visible light. The lengths of waves of different colors are shown in Fig. 398.

As a first step in the study of light and color you should make some observations. Place a glass prism in the path of a beam of bright light, as shown in Fig. 399. When the light falls upon a piece of white paper or on the wall, you may see the colors of the spectrum arranged in order from red to violet.

White light is a mixture of light waves

What causes the spectrum? The explanation lies in the fact that ordinary white light is a mixture of light waves of all the range of wave lengths included in visible light; that is, it is a mixture of light waves ranging in length between about 0.0004 and 0.0008 millimeter. You may remember from previous study that the speed of all these waves, regardless of length, — in fact, the speed of all forms of radiant energy, — is the same through empty space. Notice especially the words *through empty space*, for they are part of the answer. Even air has some effect in slowing down the speed of light waves. Now come back to your prism. When the waves pass through this piece of glass, they are not passing through empty space but through a transparent substance. Here they

Light travels more slowly through transparent substances than through empty space

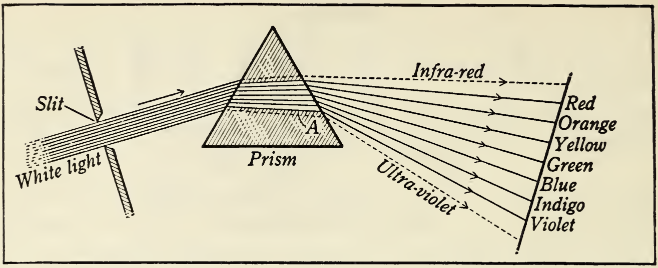


FIG. 399. The Colors of a Spectrum are caused by a Bending of the Light Rays as the Light passes through a Spectrum

travel more slowly than through space, and the shorter waves are held back more than the longer ones. In order to understand the prism, it will be necessary to study Fig. 399 and your own prism very carefully. Keep in mind that if light traveled through glass with the same speed as through air, nothing would happen and no spectrum would be formed.

The colors of the spectrum are separated by a prism because rays of different wave lengths travel with different speed through glass

Notice, however, that the beam in the figure strikes the prism at a sharp angle and that the light on one side of the beam enters the glass before the light on the other side enters. The glass holds back the light (slows its speed). Thus the light which enters first is held back first. This turns the beam away from a straight line, as shown in the figure. In the glass the longest waves move the fastest, and consequently their direction is changed least. The shortest waves move the slowest, and their direction is changed most.

Besides, since the glass is in the form of a prism, the waves whose direction is changed most must pass through the greatest thickness of glass, as in *A* of the picture.

When the beam comes out on the other side of the prism, the waves which travel fastest through glass (that is, the longest) come out first and continue from the glass with

the speed with which they traveled before entering the glass. The waves which travel slowest in the glass (that is, the shortest) are held back the most. This causes the ray of shortest wave length to turn most from the straight line along which it was traveling before entering the prism. All the rays as they entered the glass were traveling along parallel lines. After they leave the glass, they travel in straight lines, but all have been turned from the lines along which they were traveling when they entered the glass. Since the rays of longest wave length are turned least and the rays of shortest wave length are turned most, the rays are spread out, arranged in order of wave length from longest to shortest. The longest waves produce red, and the shortest waves produce violet. The other colors range in wave length between these two extremes. When the beam falls on a white surface held some distance from the prism, you recognize the colors of the spectrum.

Some substances absorb all or part of the light rays; others reflect them

Now let the light fall upon a piece of brilliant-red paper. The effect will show more clearly if the observations are taken in a darkened room. In this case the red is clearly visible. If the paper is a pure red, no other color than red will be seen. In the same manner try a sheet of blue paper. Now only blue is clearly visible. You may continue these observations with as many different colors of paper as you have. The striking thing in these observations is that the color which appears clearest on the colored paper is the same as the color of the paper. What happens when you use a piece of black paper? In the case of black no colors appear; all are absorbed.

The explanation of these observations is that a colored object reflects only light of a certain wave length. The composition of the substance is such that all other rays are absorbed. A blue dress, for example, is blue because the dye in the dress reflects only the wave length of light which gives the sensation of blue. Similarly a red dress reflects

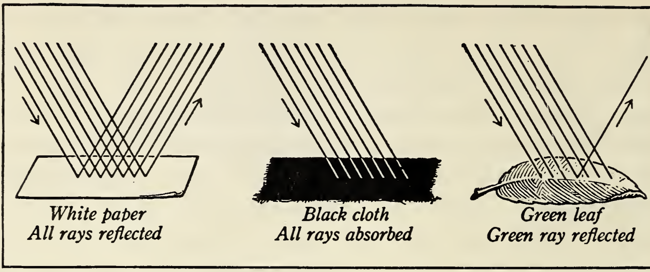


FIG. 400. The Color of a Substance is Due to the Character of the Light which it Reflects

only the wave length that gives the sensation of red. The white object reflects all wave lengths. The black object absorbs all of them. The sensation which is interpreted as white is a result of the influence of all the rays mixed together in the same manner as they are in sunlight. The sensation which is interpreted as black is a result of the fact that a black object reflects no colors. Perhaps Fig. 400 will make this clearer.

Thus you see that all color is really due to the fact that radiant energy of different wave lengths has a different effect on the retina of the eye. Differences in color are caused by differences in the structure, composition, and properties of various substances.

B. What are Infra-Red and Ultra-Violet Rays?

In your experiment with the prism you learned that the longest waves of visible light are the red, and the shortest ones are the violet. These are not the extremes of the rays received from the sun.

There are waves in the sun's rays coming to the earth that are longer than red, and waves that are shorter than violet. We do not call them waves of light because the eye is not sensitive to them. If you could explore the spectrum

FIG. 401. ISAAC NEWTON, *who first stated the Principle of Gravitation (1642–1727)*

JUST A HUNDRED YEARS after the death of Copernicus and in the same year that Galileo died, Isaac Newton was born in England. During this century scientific knowledge had increased by leaps and bounds. Galileo had first turned the telescope toward the heavens. The Copernican theory had been accepted by scientists. Kepler had stated his laws of motion, while Tycho Brahe in his fine new observatory in Denmark had studied the motion of comets and new stars · Newton was born on Christmas Day, 1642, a three-pound babe whom no one expected to live. His people had all been more or less successful farmers, and it was natural that he should be one. But all his interests seemed to center about hard problems in mathematics. He went through college, and at twenty-six he became a professor of mathematics at Cambridge University · It has been said that Newton discovered the principle of gravitation from observation of apples as they fell from a tree. This is probably not true at all. Yet it is true that the principle was worked out from carefully controlled observations. Through the use of mathematics Newton extended the laws of motion already discovered by Kepler. He explained the cause of tides. He made the first reflecting telescope. He invented the calculus, a method for solving some particularly difficult problems in mathematics. He had a notion that light was made up of very tiny particles, which he called corpuscles. Today leading students of physics are wondering if in a sense he wasn't right · Isaac Newton was one of the most brilliant men who ever lived. He was knighted by the king, and he was buried with honor in Westminster Abbey.

with a photo-electric cell, you could find plenty of evidence that there is radiant energy outside the range of the colors. The waves longer than those that produce the sensation of red are called infra-red. Those shorter than the ones that produce the sensation of violet are the ultra-violet. In the study of ultra-violet rays you must use a quartz prism because these rays are unlike light and will not pass through ordinary glass. They do pass through quartz very much as light does.

There are some rays that are invisible

The shortest waves reaching the earth from the sun have a wave length of about 0.0003 millimeter. The longest waves are of about 0.0025 millimeter. Those shorter than 0.0004 millimeter, that is, shorter than the waves of violet light, are within the range of the ultra-violet. Those longer than 0.0008 millimeter, that is, longer than the waves of red light, are within the range of the infra-red. The longest waves that reach the earth from the sun are about eight times as long as the shortest.

The full effect of infra-red rays is not yet known. It has been found that if a camera is fitted with a filter that allows only infra-red rays to pass through, clear photographs may be secured of objects at a great distance. Such photographs may be taken in darkness if infra-red rays are present. Infra-red does not produce light, for it does not affect the retina. While these rays are invisible to the human eye, they may be recorded by specially prepared photographic plates. The picture at the left in Fig. 402 was taken with a regular camera and film. The one at the right was taken with a special filter and film sensitive to infra-red rays. Do you see any differences? One reason for the differences is that infra-red rays penetrate fog better than ordinary light does.

Do all kinds of rays given off from the sun reach the earth? The proper answer to this question is "no." There can be no doubt that rays of shorter and of longer wave lengths

Ewing Galloway Wide World

FIG. 402. Infra-Red Rays penetrate Fog and make Clear Photographs Possible

These two pictures were taken from approximately the same distance. The one at the left was taken with a regular lens; the one at the right, with a lens sensitive to infra-red rays

than those that reach the earth are given off by the sun. The ones which can be identified on earth are those which pass through the atmosphere. Other rays, it is believed, are absorbed in the thin atmosphere of high altitudes, perhaps some hundred miles above the surface of the earth. The absorbing of the infra-red radiation by the thin atmosphere of high altitudes probably heats the upper air to a higher temperature than the air at the surface of the earth is heated. These rays and others may affect the upper air in other ways.

Some solar radiation does not reach the earth

C. Why does a Microscope make Things that are Near appear Larger?

In your study of the human eye you learned that the lens in the eye brings light to a focus so that images of objects are formed on the retina. The optic nerve is able to register the effect of these images on the brain, and this gives us the sense of sight. The lens in a camera (as you can see from Fig. 403) is similar to the lens in the eye.

Light passing through the lens is focused upon the film. The image, as you have learned, is recorded in a chemical effect that is produced on the film. This effect from the image appears when the film is developed. Suppose we study lenses at greater length.

The lens of a camera is similar to the lens in a human eye

Use a lens of a reading glass like the one you used in the study of the eye. Let the light from the sun pass through the lens and on to the table top. You probably know that light may be focused, as shown in Fig. 404. The point at which the parallel rays come together is called the principal focus of the lens. The distance from the lens to its principal focus is the focal length.

A lens brings the rays of light to a focus

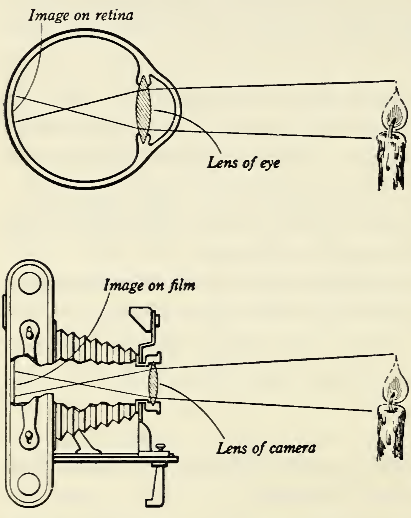


Fig. 403. The Lens in a Camera is Similar to the Lens in the Human Eye

What points of similarity can you find?

You know, too, that infra-red waves, that is, the waves that produce heat, are focused just the same as the light waves are, for the spot on the table at which the rays are focused is intensely heated. The diagram shows the shape of the lens. It is double convex; that is, it curves outward on both sides. Why are light rays brought to a point with a lens like this one?

In your study of a prism you learned that light is bent from a straight line as it passes through glass. In a prism the light is turned toward the thick part

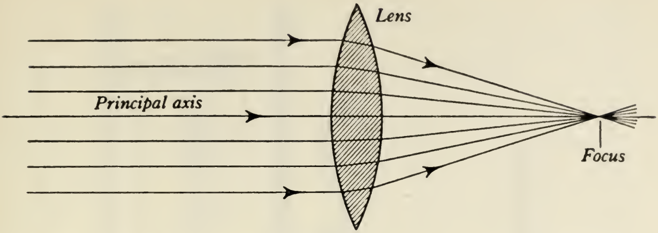


Fig. 404. Parallel Lines are brought to a Focus after passing through a Lens

The diagram illustrates the principle of an ordinary reading glass

of the glass. So it is in a lens. In a convex lens the thickest part of the glass is in the center, so all the rays that fall on the glass are turned toward the center. Since this is the case, you may see why parallel rays come to a point; that is, why they are focused after passing through a convex lens. The lens of a camera is a convex lens, similar to the one in the reading glass. Use a candle flame as shown in Fig. 405 to study the property of the lens that makes it useful in a camera. You may be surprised to see that the image of the candle is inverted, or turned upside down. Why is it inverted?

Light is turned from a straight line and brought to a focus by a convex lens

In Fig. 406 a straight line, AB, is drawn to represent the position of the candle, and another line, $A'B'$, to represent the position of the image. Of course, light rays come off from every point on the flame and move outward in every direction. We are interested just now in those rays that pass through the lens. The line through O and F in Fig. 406 is called the principal axis of the lens. A line is drawn parallel to the principal axis to represent one ray of light from A. Another is drawn through the center of the lens to represent another ray from A. The lens is curved so as to make these two rays come together at A'. Similarly any other ray of light from the point A that falls upon the lens will

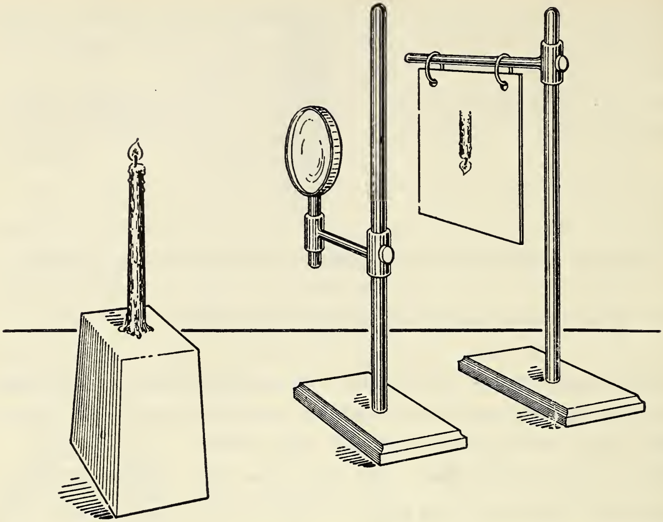


Fig. 405. An Image of the Candle forms on the Cardboard

The convex lens is an ordinary reading glass

pass through A'. An image of the point A will form on a piece of white paper at A'. Similarly an image of B will form at B'. The image of points between A and B will form between A' and B', so that there will appear on the piece of paper a complete image of the object AB.

In this case the distance from the lens to the object is a little greater than the focal length. The distance of the image from the lens is more than twice the focal length. The image is larger than the object. Using this lens, the condition could be reversed. If the object were set at the position indicated as "image," the image would appear in the position indicated as "object." In this case the image would be smaller than the object.

How does the distance from the center of a convex lens to its focus differ from the distance from its center to the position where the image forms? Notice that all *parallel*

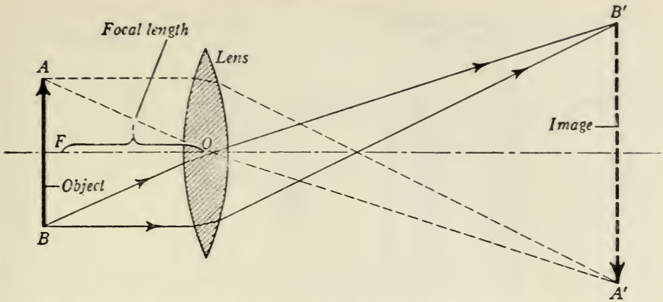


FIG. 406. This Diagram explains how the Image shown in Fig. 405 is Formed

The object corresponds to the candle

rays come to a point at the focus. The image distance is the distance from the lens at which all the rays reaching the lens from the same point (point A, for example, in Fig. 406) will come to a point after passing through the lens. Obviously the rays from point A cannot be parallel rays.

The distance from the lens to the object must be greater than the focal length. If the object is very near the focal length, the image is very large. If the object is very far away, the image is very small. If the distance between the object and the lens is less than the focal length of the lens, no image to correspond to $A'B'$ in Fig. 406 is produced. Another effect is produced, however, which we shall study in a moment in connection with the simple microscope.

The size of the image produced by a lens depends in part upon the distance of the object from the lens

The lens in Fig. 407 is similar to the one used in a picture lantern. The "object" in a picture lantern like the one in Fig. 408 is a lantern slide. This is brilliantly lighted by a powerful lamp. The two lenses at the left of the slide serve merely to concentrate the light on the slide. The image on the screen is formed by the lens at the right of the slide. The slide is fairly close to this lens, just outside the principal

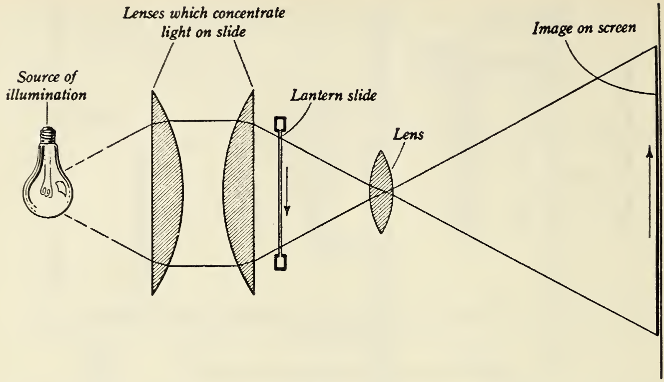
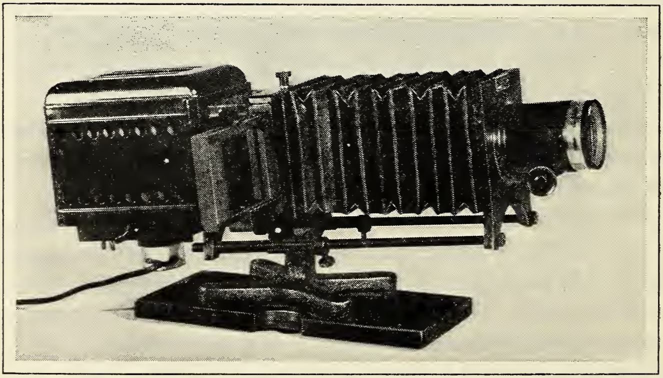


Fig. 407. In a Picture Lantern Light is concentrated on the Slide and a Bright Image of the Picture on the Slide forms on the Screen. Compare this with Fig. 406

focus. The image on the screen is far away from the lens and consequently very much enlarged.

Now use your reading glass again, this time as a simple magnifier. Place a penny on the table and view it through the glass. Why does it appear large? Again follow some lines that show the direction of rays of light from the



Ewing Galloway

Fig. 408. A Picture Lantern is an Arrangement of Several Lenses

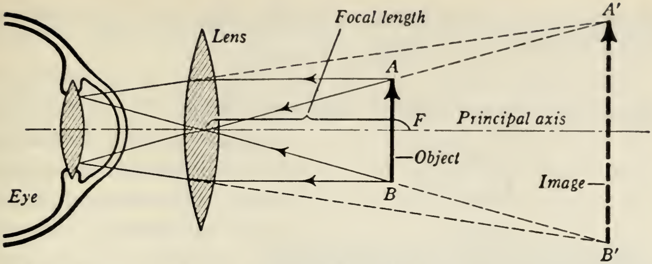


FIG. 409. When an Object is viewed through a Reading Glass, it appears Greatly Magnified

penny. The line *AB* in Fig. 409 represents the diameter of the penny. Notice in this case that the distance from the object to the lens is *less* than the focal length of the lens. One line from *A* is drawn parallel to the principal axis of the lens. Another line is drawn through the center of the lens. Because of the lens these two lines do not seem to come from the point *A*. They seem to come from the point *A'*. Similarly all the rays from *A* would seem to come from *A'*. For the same reason all the rays from *B* would seem to come from *B'*. All the light passing from the penny through the lens is spread over a circle whose radius is *A'B'*. Therefore the penny seems much enlarged.

A reading glass is a simple magnifier

What is a compound microscope? A single lens like the one you have just used may be called a simple microscope. A compound microscope, shown in Fig. 410, is one with at least two lenses. The lens nearer the object, the objective, is one of short focus. The object to be examined is mounted on a glass slide and placed just a little farther from the lens than the focal length of the lens. This arrangement is the same as shown in Fig. 406, and an enlarged image forms at about the position marked "image" in Fig. 410. But the distance between the image and the eyepiece lens is less than the focal length of the lens. This

A compound microscope is a combination of lenses

arrangement is the same as in Fig. 409, and the eyepiece lens magnifies the image.

The object shown in Fig. 410 may be 1 millimeter in diameter. In a typical case the image formed by the objective lens would be 32 millimeters in diameter; and when this image is viewed through the eyepiece, its diameter would appear to be ten times greater than it appears to be in the image. The objective magnifies thirty-two times, and the eyepiece magnifies ten times; therefore if the object is 1 millimeter in diameter, it would appear through the microscope to be 320 millimeters in diameter. In other words, the object is magnified three hundred and twenty times.

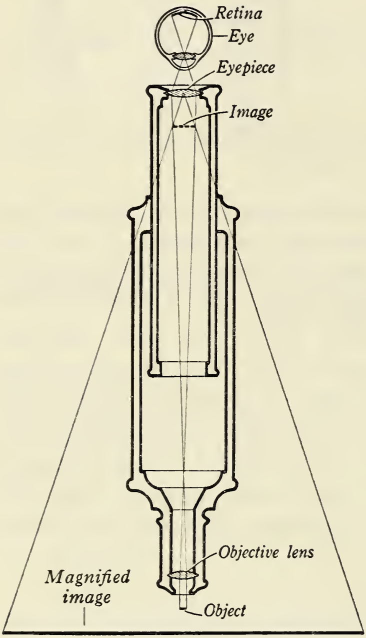


Fig. 410. In a Compound Microscope the Lenses are so combined as to Greatly Magnify the Object

What are the limits within which an object can be magnified? We see an object by the light that comes from it. As the object is enlarged more and more, the light from a unit area becomes less and less. As an object is more and more highly magnified, more and more light is required to make it visible. There is, of course, a practical limit beyond which it is useless to try to magnify any object. Compound microscopes have a concave mirror beneath the objective which serves to concentrate light on the object.

D. How does a Telescope make Things that are Distant appear Larger?

The simplest telescope (called a refracting telescope) is, in some features, similar to a microscope. There are two double-convex lenses: a large one with a long focal length at the upper end of the instrument, and a small one at the lower end. In the telescope of the Yerkes Observatory (shown in Fig. 411) the outer lens is 40 inches in diameter. Its focal length is more than 60 feet. A bundle of light 40 inches in diameter may enter the lens from a star. The star is so far away that the rays from it are almost parallel. The image of this point of light forms at the focus of the lens. The star is not magnified. It remains a point of light, but it is a much brighter point when seen through the telescope. Images of other stars within the field of the telescope are also formed at the focus of the lens. The moon is of course much nearer than the star; yet it is so far away that rays from it are almost parallel. In a similar manner, then, images of points on the moon would form at the focus of the lens. Notice that the image forms at the focus only

Fig. 411. The Refracting Telescope is the Simplest Form of Telescope

This picture shows the instrument of the Yerkes Observatory

The simplest form of telescope is the refractor

when the source of light is so far away that the rays from it are almost parallel. The image formed at the focus is magnified by the eyepiece lens. When a lens of 0.25-inch focal length is used as the eyepiece of the Yerkes telescope, the object is magnified three thousand diameters. Two stars seen through this telescope would seem to be three thousand times farther apart than they seem to be when seen with the naked eye. Venus has a noticeable diameter. When seen through this telescope, the moon would appear to be three thousand times larger than when seen with the naked eye. In a refracting telescope the big lens makes a bright image of the distant object. It is formed in a position in which it may be magnified by the lens or lenses in the eyepiece.

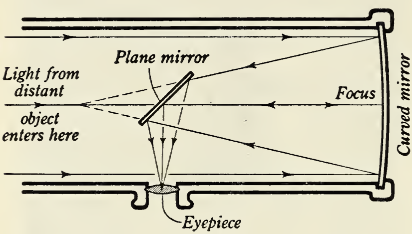


FIG. 412. In a Reflecting Telescope the Light is gathered by a Mirror, after which the Image is Magnified

The largest telescope in the world today is the one at Mt. Wilson in California. It is a reflecting telescope. Light from a distant object is brought to a focus by means of a curved mirror. The mirror of the Mt. Wilson telescope is 100 inches in diameter.

A reflecting telescope uses a mirror to gather light. The image is then magnified

What is meant by *reflection*? When light falls upon an ordinary plane mirror, it is reflected, and you can see your image in the glass by reflected light. Suppose the mirror has a curved surface like the one in Fig. 412. The light is reflected so as to bring it to a point. The position at which the light comes to a point is the focus of the curved mirror. In the reflecting telescope, light from a distant object is reflected to a plane mirror that is set in position as shown in Fig. 412. Light is reflected from the plane mirror into the eyepiece, where the image is mag-

nified just as in the eyepiece of the refracting telescope. Photographs of heavenly bodies are made by attaching a camera to the eyepiece. The photographs of stars and star clusters shown in the next chapter were made through the Mt. Wilson telescope.

White light is a mixture of light rays of different lengths and thus of different colors. Color is produced by the properties of materials which permit them to absorb or reflect waves of different lengths. A lens focuses the rays of light to a point. Such instruments as microscopes, projecting lanterns, and telescopes are based upon applications of the principles of the lens.

Can You Answer these Questions?

1. Can you make a list of the colors in the spectrum in order, from short wave lengths to long wave lengths?

2. Why is a spectrum formed when light passes through a glass prism, but not when it passes through a pane of window glass or plate glass?

3. What is the scientific explanation of the color of a red apple, a white sheet of paper, or a black coat?

4. In what ways is the lens in a camera similar to the lens in a human eye?

5. What is the principal focus of a lens? the focal length?

6. Why is the image of an object upside down after the reflected rays of light pass through a convex lens?

7. What is the explanation of the enlarged object you see when you look at a penny through a reading glass?

8. What are the principles which explain a simple microscope? a compound microscope?

9. What is the difference between a refracting telescope and a reflecting telescope?

Questions for Discussion

1. If it is true that a cat can see in the dark better than we can, what may be a possible explanation?

2. Is black a color? white? infra-red? ultra-violet? Explain.

3. What is really meant when it is said that a camera is out of focus?

4. If you look into a convex mirror, you look much bigger than you really are. Why should this be so?

5. Can you think of any relative advantages or disadvantages of a refracting telescope as contrasted with a reflecting telescope?

6. If radio waves, like light, travel in straight lines, and if the earth is round, how is it that we can hear broadcasts direct from England?

Here are Some Things You May Want to Do

1. Set up an experiment to show that light travels in a straight line.

2. Make a pinhole camera and take some pictures with it.

3. Set up the prism experiment described in this chapter. Let the rays of light, after they pass through the first prism, fall upon another prism. Place a piece of paper behind the second prism. What colors fall upon the paper? What explanation is there?

4. Is light bent when it passes through water? How should you find out?

Chapter XXXI · How have New and Better Tools extended our Information about the Universe?

A. How did Galileo's Telescope change Men's Notions of the Earth and Sky?

When Thales was wondering about eclipses and Eratosthenes was measuring the circumference of the earth, they had no telescopes to aid them. They used only their naked eyes and inaccurate instruments for measuring angles. They had little knowledge of physics, no algebra or higher mathematics except geometry, and no knowledge of the nature of light or the structure of matter. Nor were the leaders in European universities two thousand years later much better equipped.

In 1610 Galileo turned his first telescope skyward

It was not until the year 1610 that Galileo turned his first telescope toward the heavens and witnessed phenomena that changed men's thought for all time. A few years earlier a Dutch optician had made the first compound microscope. Shortly afterwards another Dutch optician made what was probably the first telescope. Many enjoyed this new toy and talked about it.

Soon Galileo heard about this new instrument, and, thinking it would be useful to him in studying the heavens, he set about making one for himself. He soon had an instrument with which he could see objects "three times as near and nine times as large" as with his eyes alone. His most powerful instrument was one which magnified about thirty-three diameters. Some very troublesome practical difficulties had to be met before a more powerful instrument than this could be built. But this instrument, small indeed in comparison with the giant refracting telescope in the Yerkes Observatory, was sufficient to open a new world to its maker.

Galileo looked in turn at the stars, the moon, the sun, and the planets. He peered through his telescope in the direction of the Milky Way. It wasn't gas, after all! That cloudy whiteness was made up of countless points of light — stars that no one had ever known before! He looked at the moon. Its clear, bright surface was scarred and rough. It appeared to be speckled with mountains. Even the sun bore huge dark spots — and change in position of these spots seemed to show that the sun was rotating on an axis. You already know that one of Galileo's first discoveries was the phases of Venus. These had been predicted by Copernicus, but proof of the prediction had to await the telescope.

Galileo saw the stars in the Milky Way

He saw mountains on the moon and spots on the sun

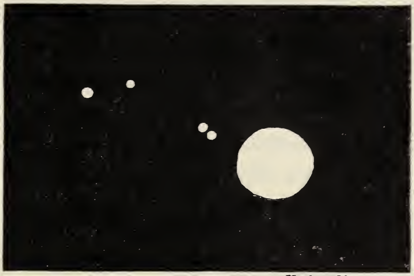
© Bausch and Lomb Optical Company

Fig. 413. Galileo was One of the First Modern Astronomers

Next Galileo looked at the planet Jupiter. Let him tell you about it in his own words:

On the seventh day of January in the present year when I was viewing the constellations of the heavens through a telescope, the planet Jupiter presented itself to my view, and as I had prepared for myself a very excellent instrument, I noticed a circumstance which I had never been able to notice before, owing to want of power in my other telescope, namely, that three little stars, small but very bright, were near the planet; and although I believed them to belong to the number of the fixed stars, yet they made me somewhat wonder, because they seemed to be arranged

exactly in a straight line, parallel to the ecliptic, and to be brighter than the rest of the stars, equal to them in magnitude. . . . I scarcely troubled at all about the distance between them and Jupiter, for, as I have already said, at first I believed them to be fixed stars; but when on January 8th, led by some fatality, I turned again to look at the same part of the heavens, I found a very different state of things, for there were three little stars all west of Jupiter and nearer together than on the previous night.



Yerkes Observatory

Fig. 414. This Observation of Jupiter and its Moons has been Important in explaining the Origin of the Solar System

These little "stars" proved to be the moons of Jupiter. Further observation showed a fourth little "star" that had been eclipsed at first by its giant planet. Fig. 414 shows a photograph of Jupiter and four of its moons, taken through the telescope of the Yerkes Observatory. Here indeed was something to talk about! A little world system out there in space behaving just as Copernicus had said the planets were behaving with respect to the sun. Was he right? Galileo, for one, believed that he was.

Galileo discovered Jupiter's moons

B. How has the Use of Mathematics increased Man's Knowledge of the Universe?

In the year that Galileo died Isaac Newton was born. Newton, during the eighty-five years of his lifetime, saw scientific thinking and scientific achievement come into their own. And his own contributions were in a large way responsible for the advance in thinking.

Newton was one of the ablest students of mathematics

the world has ever produced. The Greeks and Egyptians had known quite a good deal of geometry. They were good surveyors and good navigators. The Arabians, introducing their culture into Europe through Spain, had brought the main principles of algebra along with the Arabic numerals. Kepler was a German interested in astronomy and mathematics who lived at the same time as Galileo. He had combined algebra and geometry in such a way as to get equations that showed how the planets travel in ellipses about the sun. He measured also their relative masses and distances. He too was convinced that the Copernican theory was correct. His conviction was strengthened by his calculations, while Galileo's rested chiefly upon what he had seen with his telescopes.

Newton was a genius in mathematics

Newton, however, went far beyond these men in his thinking. He *invented* the system of mathematics called the calculus. This is a system of mathematical thinking used in work with variable, or changing, quantities. This system was extremely useful in the study of the motions of heavenly bodies. Geometry and trigonometry are the kinds of mathematics used in the study of fixed points. The calculus is the kind of mathematics which is useful in the study of objects in motion. Through the use of the calculus and with the aid of countless careful and accurate observations Newton worked out the law of gravity about which you have already learned some things. It may be stated briefly as follows: "Every particle of matter in the universe attracts every other particle with a force directly proportional to their masses and inversely proportional to their distances."

Newton worked out the law of gravity

Stated in less abstract terms, this means that everything *in the universe* pulls upon every other thing and that the force of the pull depends upon the masses of the objects, the greater masses exerting more pull on each other

than smaller masses exert on each other. Then, too, objects that are near each other exert more pull than objects far apart, and the law tells exactly how much more. Newton's equations cannot be written here, but it may give you an idea of their complex nature if we tell you that just those equations having to do with the motions of the moon about the earth and the forces exerted by the two bodies upon each other fill books larger than the one you are reading.

Such careful equations were used by others of Newton's contemporaries. You may know that his friend Halley predicted the return of a comet whose speed and path in the sky he had determined by the use of mathematics. The paths of the planets and their moons were mapped accurately, and eclipses were now predicted within a second of their actual occurrence.

As an example of the use to which mathematics may be put in astronomy let us take you for a few minutes down through the years to the middle of the nineteenth century and the discovery of the planet Neptune.

The Greeks and Egyptians had known and named five planets — Mercury, Venus, Mars, Jupiter, and Saturn. Sir William Herschel had discovered Uranus with his telescope.

Mathematics was an aid to the discovery of Neptune

The next planet, Neptune, was discovered with the aid of mathematics and was known to exist before it had been seen. Some fifty years after the discovery of Uranus astronomers began to realize that their calculations regarding the path of Uranus were not quite in agreement with observations. The positions of Uranus at various times had been observed and recorded. Its distance from the sun had been figured. Its mass and size had been calculated, and its path around the sun mapped. All this was done by means of mathematics; and since the best students of mathematics in the world had worked on the problems, the figures were probably correct. Nevertheless Uranus was not fol-

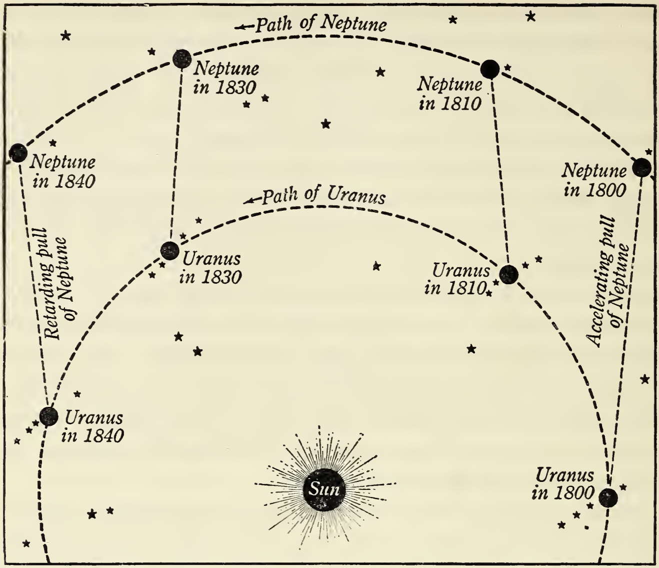


FIG. 415. Although Neptune is Invisible to the Naked Eye, it was Located and its Orbit was drawn from Study of its Effects on the Orbit of Uranus

lowing exactly in the path that was predicted for it by these calculations. Scientists suggested as a theory to explain these irregularities the supposition that there was another planet beyond Uranus and that this unknown planet was affecting the path of Uranus. Newton's law of gravity says that every particle of matter attracts every other particle. If the unknown planet were big enough or near enough, then it could exert just enough pull on Uranus to keep it from moving in the path along which scientists thought it should move. It was necessary to test this theory by careful study.

A theory was suggested which predicted the position of an unknown planet

Accordingly two young students of mathematics, both

just out of college, Leverrier in France and Adams in England, although unknown to each other, set out with paper and pencil to locate the new planet. Their calculations showed that if there was such a planet it must be in a certain position. They located this position by mathematics and suggested that this position be carefully explored with a telescope. Leverrier wrote to a friend of his who worked in an observatory in Berlin — a Dr. Galle. He asked Galle to look through his telescope for the planet, and he gave him instructions as to where to look. Galle looked, and there it was. His prompt action won for him and his friend the credit of making the discovery. People all over the world were interested in the work of Adams and Leverrier. Through the use of mathematics Leverrier had told where to find a planet more than two billion miles from the earth, and Galle, following his instructions, had found it. The orbits of these planets are shown in Fig. 415.

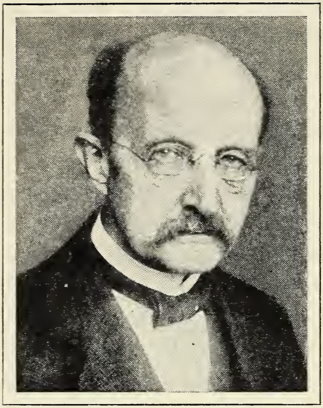
Neptune was found in the position predicted for it

A ninth planet, Pluto, was discovered by similar methods in 1930. This little planet is nearly four billion miles distant from the sun and appears merely as a point of light when viewed through our best telescopes. Its path has been charted with sufficient accuracy to show that it is a planet, revolving about the sun once in about two hundred and twenty-five years.

The position of Pluto was predicted from theory

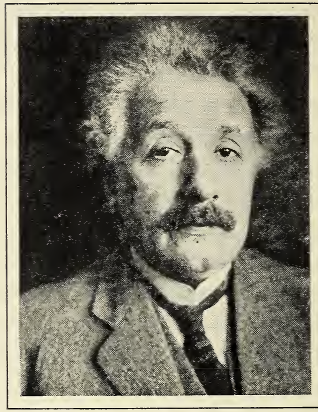
As one more illustration of the use of modern mathematics in astronomy, let us take you out beyond the solar system to that brightest of all stars, Sirius. This star is nearer to us than any other bright star except one, and its light takes only a little over eight years to reach us. As star distances go, this is very near; and a careful astronomer can measure its motion from year to year. In a thousand years its motion as measured from the earth will be through a distance equal to the apparent diameter of the moon.

But over a century ago careful observation showed that



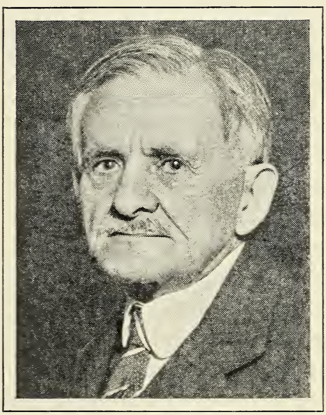
International News Photo

Max Planck



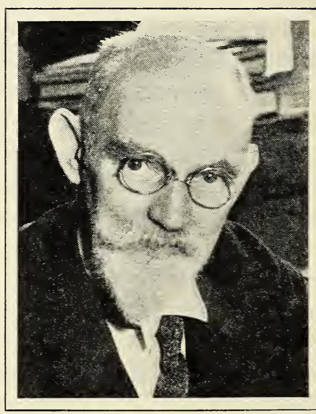
Ewing Galloway

Albert Einstein



Underwood & Underwood

Albert A. Michelson



Wide World

Willem de Sitter

FIG. 416. Famous Mathematicians and Scientists

Mathematics is used as a tool for testing and refining scientific theories

Sirius was not moving regularly. Calculations showed that it was being pulled from its path apparently by some other object nearly as large as itself but as yet undiscovered. Indeed, Sirius seemed to be revolving, with its unknown companion, about a common center of gravity once in fifty years. Sirius is a star having a diameter half as large again as the sun, and one would expect that only a rather large star could exert enough force upon it to pull it thus far out of its course. No such object could be seen.

Sirius has a strange small companion discovered by use of mathematics

In 1862 an American telescope-maker turned his newest and best instrument upon Sirius. There was the companion star. But a strange little companion it was! A faint white dwarf star, the diameter of which is about twice the diameter of the earth, but whose mass is nearly four thousand times as great as the mass of the earth. The average density of this companion to Sirius appears to be about 8000 grams per cubic centimeter. One cubic inch of this star if brought to the earth would weigh about 270 pounds. How may this be explained? Well, that is difficult to tell. But the many calculations which have been made suggest that such a body does really exist.

Nor are these all the uses of mathematics in modern astronomy. Telescope-makers must know exactly what shape to make their mirrors and lenses, and in what position to mount them. This work requires expert use of geometry.

Distances to the nearer stars, to the moon, and to the planets may be determined by careful measurements of angles, much as surveyors measure distances on earth. But the distances in space are so great that the utmost care must be exercised in taking measurements. You have doubtless read about the feats of Einstein, Planck, Michelson, de Sitter, and other leaders in the field of mathematics. Much of their work has been in the mathematics of astronomy. The modern astronomer is no longer just a "stargazer." He must be an able student of mathematics as well.

C. What have Modern Telescopes Revealed?

Bigger and better telescopes reveal new wonders

It is a far cry from Galileo's first little telescope that would magnify an object nine times to the present giant instruments "equivalent to a human eye one hundred inches in diameter." It is not strange that bigger and better instruments have revealed new and unimagined sights — double stars by the thousands, island universes whose light takes millions of years to reach us, unknown moons and planets.

Fig. 417. The Moon would appear like this from a Distance of One Thousand Miles

All the largest of our modern telescopes are reflectors. It is a big task to prepare great pieces of glass for these large mirrors. A new reflector, twice the diameter of the one now at Mt. Wilson, is in process of construction. The reflector for this new instrument was briefly described on page 284. It will take several years to build this 200-inch instrument, which will weigh nearly 1600 tons — mirror, mounting, and all. What new mysteries may be revealed? Just by way of illustration, this telescope will bring the moon within an apparent distance of 24 miles of the earth! The surface of the moon in Fig. 417 is as it would appear if the moon were seen with the naked eye at a distance of 1000 miles. It is expected that with this new instrument astronomers will be able to explore and

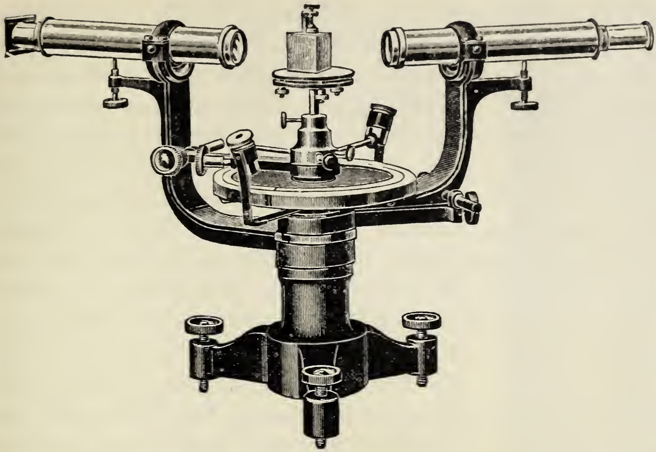


Fig. 418. The Spectroscope has aided Astronomers in finding out about Distant Heavenly Bodies

photograph objects three times as far away as can be reached by the Mt. Wilson telescope. Already explorations extend into space many million times farther away than the sun. What new things will be revealed by going three times farther? Does space go on and on? Are there more or fewer stars and galaxies at greater distances? There are hundreds of unanswered questions. Astronomers await with intense interest an opportunity to take photographs through the new telescope, and are eager to see what the pictures will show.

D. What is a Spectroscope, and How has it aided the Progress of Astronomy?

We are indebted to the telescope and its assisting camera for some of our knowledge regarding star distances, sizes, temperatures, and speeds. But we are no less indebted to a second less well-known instrument called the spectroscope. Fig. 418 is a photograph of this instrument.

The spectroscope is an instrument used in the analysis, or study, of light. You know that white light in passing through a glass prism is broken up into various colors. Each of these colors may tell a definite story about the object that gave off this light, no matter how far distant the object may be. It is more than two hundred and fifty years since Newton broke up white light by passing it through a glass prism. About fifty years after Newton's study of white light Fraunhofer discovered that the sun's spectrum is not continuous but crossed by many dark bands. The spectrum of the sun is shown in Fig. 419. What these dark bands mean was explained by two later scientists, Bunsen and Kirchhoff, who thus opened up an entirely new field, that of astronomical chemistry.

The spectroscope contains a prism which breaks white light into colors

The sun's spectrum is not continuous

There are four important principles of spectrum analysis, which may be briefly summarized.

1. A solid or liquid substance that is hot enough to radiate light gives a continuous spectrum, the colors depending upon its temperature. An object which is just red-hot shows the colors at the red end of the spectrum. As it is heated to higher temperatures, it shows more of the colors toward the violet end of the spectrum. It is easy to see that the spectrum from a star gives an indication of the temperature of the star. If the spectrum shows mostly red, it is a relatively cool star.

There are four principles of spectrum analysis

2. A hot gas under low pressure gives a spectrum that consists of discontinuous bright bands whose positions depend upon the chemical composition of the gas.

Sodium in the form of gas gives a spectrum with definite bright yellow bands. Lithium gas gives one especially bright red band. There is a characteristic spectrum for each chemical element, and by means of it each chemical element may be identified. The spectroscope is therefore a useful instrument in chemical analysis of gaseous substances.

3. When white light passes through a gas and then through a spectroscope, dark bands may be seen in the resulting spectrum in the exact positions where bright bands would appear if the gas were itself the radiating source. For example, light from an arc lamp passed through sodium vapor will show dark lines in positions corresponding to the bright lines given off by sodium. The dark lines which show in the spectrum of the sun, the Fraunhofer lines (or bands), tell to the one who is trained to interpret them the composition of the sun's atmosphere. To one who understands their meaning, each of these dark bands shown in Fig. 419 tells something about the composition of the sun's atmosphere.

FIG. 419. Elements in the Sun's Atmosphere cause the Dark Bands on the Sun's Spectrum

4. If an object that is radiating energy is moving *toward* the spectroscope, its lines are shifted toward the violet end of the spectrum, the amount of shift depending upon the speed of approach. If the object is moving *away* from the spectroscope, the shift is toward the red end of the spectrum.

This same effect may be illustrated by sound waves. The pitch of a whistle when it is moving rapidly toward you is higher than it is when the whistle is stationary. If the whistle is moving away from you, the pitch is lower. This phenomenon when associated with either light or sound is called, from the man who first described it, the Doppler effect. A good illustration

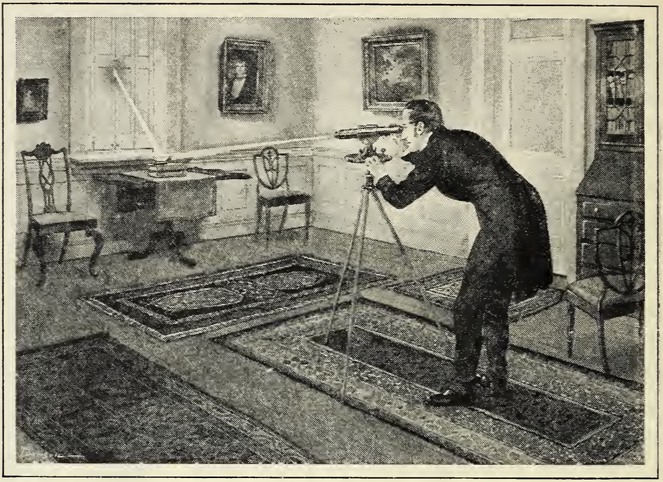


FIG. 420. JOSEPH FRAUNHOFER, *who brought the Study of the Stars into the Laboratory (1787–1826)*

MEN OF ALL AGES have wondered about the stars. But few were so bold as to believe that they would ever really *know* the compositions, speeds, or distances of these heavenly bodies. Today we have all the tools for getting this information, and for them we are indebted, perhaps more than to anyone else, to a crippled young Bavarian optician, a maker of glasses, who died before he was forty · Joseph Fraunhofer was the son of a glazier. The father died when the lad was eleven. Shortly afterwards young Joseph was crippled in the ruins of a falling building. But this was in one sense a stroke of luck, for a sympathetic witness gave the boy some money. With part of this he bought some clothes and a book on optics, which is the science dealing with the nature of light and the phenomena of vision. After completing an apprenticeship, he set up for himself as a maker of optical glasses · Studying on the side to get the mathematics he needed to grind good lenses, he soon achieved fame for his microscopes and telescopes. He improved the telescope by combining lenses so shaped that the images were no longer blurred by colored edges · Working with glass prisms, he noticed dark lines in the solar spectrum. These had been seen before but not understood. Fraunhofer guessed that each line had a definite meaning and that they were all related in some way to the chemical composition of the sun. Each dark line he charted and labeled. He compared the solar spectrum with spectra of the stars. The simple glass prism became in his hands the spectroscope that interprets the secrets of the heavens. He made possible a chemistry of the stars.

is the apparent change in pitch of the horn of an automobile as the car on which it is sounding speeds rapidly past you.

These laws have been worked out in the laboratory through careful observations and by checking with known facts. You may believe that it was no small task, and many scientists have worked upon it. But think for a few minutes how these laws may be used.

The spectrum of a star reveals many secrets to a trained astronomer

The spectrum of a star will tell us its temperature, and how far away it is. It will tell us whether the star is coming toward us or moving away from us, and how fast. It will tell whether it is double, for in that case two spectra are shown. It will tell the chemical composition of the star, and what elements are most abundant. What a useful instrument the spectroscope is! All these secrets and many more will it reveal to the astronomer who is trained in its use.

In all the sky there are about five thousand stars bright enough to be seen with the naked eye. Careful observers have counted a few more than a thousand from one position. A modern telescope may reveal a billion. It is equivalent to an eye a hundred inches in diameter. Coupled with the camera it has extended the known limits of the universe by millions of light-years. The spectroscope reveals the composition of stars, their temperatures, sizes, and velocities. Mathematics interprets the facts revealed by these instruments.

Can You Answer these Questions?

1. What were the chief differences between Galileo's simple telescope and a refracting telescope of today? a reflecting telescope of today?

2. Can you give in simple terms some examples which illustrate Newton's law of gravity?

3. What evidence is there in the movement of the heavenly bodies which supports Newton's law of gravitation?

4. How does the spectrum of a star indicate the temperature of the star?

5. How may chemical elements be identified by their spectrum? Of what help is this in astronomy?

6. What happens to the spectrum of white light if the light is first passed through a gas and then through a spectroscope? How does this aid in studying far-off heavenly bodies?

7. What happens to the lines of the spectrum if the radiating object is moving toward the spectroscope? away from the spectroscope? What applications may be made of this in astronomy?

Questions for Discussion

1. There is a limit to the making of microscopes that will "see" smaller and smaller things. Is there a limit to the making of telescopes that will "see" farther and farther? Explain.

2. What difference do you think the increasing knowledge of astronomy makes to us?

3. Do you think it is correct to say that a person *invents* a system of mathematics, such as the calculus?

4. Why does not the force of gravitation upon earth pull the moon to the earth?

5. If the moon is responsible for tides on earth, why are there two high tides every day?

Here are Some Things You May Want to Do

1. Pass the light from a bunsen burner through a glass prism and observe its spectrum. How does it differ from the spectrum of white light?

2. On page 701 you find references to several scientists. Prepare class reports on their life and work.

3. You have learned about two important instruments used in observations made by astronomers. There are others, however, including the interferometer and the bolometer. See if you can find out how they are used, and what their use has revealed.

Chapter XXXII · What is the Origin of the Solar System, and What lies in Space beyond It?

Second only perhaps to his curiosity about his own origin and ancestors has been man's interest in the question of the origin of the earth. How old is it? What was it like when it was young? How did it come to be? Will it always remain as it is now? Many have been his guesses to explain these things. He sees about him a changing world. It is but natural to inquire how and when these changes began.

A. What is the Origin of the Earth ?

The sun is very, very old

At the present time the most probable theory in answer to these questions seems to be one developed by Professors Chamberlin and Moulton at the University of Chicago. It supposes that the earth and all the other planets, together with their satellites, were once a part of the sun. This sun was a star of medium size and brightness, speeding along through space as it is today and as it had been for no one knows how long before.

A few billion years ago, according to the theory, a second and probably larger star passed near this sun of ours. By near we mean within a billion miles or so, probably as near as the planet Neptune is today.

Some few billion years ago a star passed near the sun

This second star was large enough and near enough to exert a strong gravitational pull upon the sun. It pulled up in huge bulges a small part of the outside of the sun's matter. This was chiefly gaseous then as it is now. One bulge formed on the side that was toward the star, and a second bulge formed on the opposite side — in much the same way that the moon causes tides upon the earth today.

But the unknown star was traveling in one direction and the sun in another. The tides became streamers extending out from the sun in two long spiral arms. Matter was pulled out of the sun. Perhaps similar spirals were developed in the other star, although we have no way of knowing. All we can do is to imagine what happened.

The planets were pulled from the sun

At last the star had passed by, and finally it no longer exerted any noticeable pull upon the sun. After it had passed, the particles in the spiral arms of the sun were influenced only by the sun itself and by each other. They had been hot like the sun when they escaped from it; but now they cooled quickly, since they were small and there was nothing to keep them warm. Thus they became countless bits of solid rock, like meteors, swarming about the sun. They did not fall back into the sun, for they were traveling too rapidly, owing to the pull that had been given them by the unknown star. As a consequence of the combined forces of gravity and their own speed they now revolved about the sun in elongated ellipses crossing each other's paths rather frequently.

Planets were once much smaller than they are today

These bodies have been called planetesimals, since they were like little planets. Some, of course, were larger than others. Therefore as they traveled through space and met smaller bodies, they would attract them because of their greater gravity, just as the earth attracts meteors today.

These largest planetesimals would become larger and larger, for each falling meteor would add to their mass. A small earth, perhaps not much more than half its present diameter, was one of these planetesimals that grew larger by catching smaller neighbors. Jupiter, happening to be larger to begin with, caught even more than the earth. Occasionally a neighbor might be trapped but not destroyed, and from then on become a moon revolving about the larger body.

The larger planetesimals attracted the small ones

After many, many millions of years the paths of the larger bodies became fairly well cleared of meteors, and frequent collisions had reduced their orbits to nearly perfect circles.

Planetesimals grew larger

Now as the earth, together with other planets, became still larger, it began to be warm again, for crashing meteors converted energy of motion into heat energy. The radioactive elements (radium, thorium, uranium, and so on) in the rocks of the earth also gradually broke up and produced heat which could not easily escape. Finally the earth became large enough (and so had enough gravity) to hold an atmosphere. This atmosphere probably came from meteors and surrounding rocks heated to the glowing point by the force of the collision as the meteors struck the earth's surface. After changes like this, conditions on the surface of the earth became favorable for life.

The earth became large enough to hold an atmosphere

The tidal theory suggested by Sir James Jeans gives a similar explanation of the origin of the bodies of the solar system. One important difference in the two theories is that Jeans supposes a slow cooling of the planets. In this particular the theory of Jeans is similar to the older theory of Laplace, which is stated briefly below.

B. Do Facts fit the Theory?

Does this account sound like some strange product of the imagination, some fairy tale with no foundation? Sometime we may learn, to be sure, that it is not entirely true, but the facts as we know them today lead us to believe that the theory is probably correct, at least in its general plan.

It is certainly a fact that our sun is one of many stars that move through space in various directions. There must necessarily be times when two stars will come within close enough range of each other to set up tides as supposed in this theory. On the other hand, such chance meetings will not be frequent. Considering the size of our particular

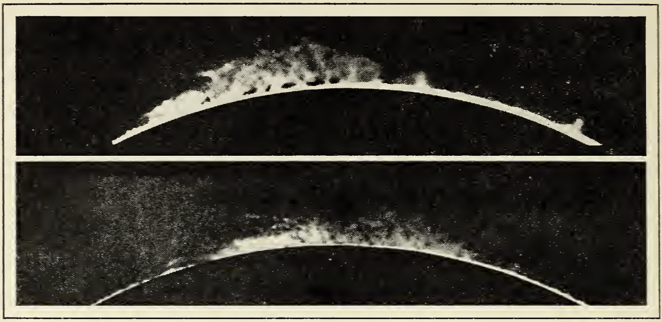


FIG. 421. The Gravitational Attraction of a Passing Star would pull the Hot Masses of Matter shown above away from the Sun

The upper and lower photographs were taken one day apart

part of the universe and the number of stars in it, students of mathematics have figured that just on the basis of chance our sun is likely to approach near enough to another star to cause trouble once in about one quadrillion years. This is a million billion years. The earth itself is believed from evidence in its own rocks to be in the neighborhood of two billion or three billion years old — still young, you see.

The sun is likely to pass near another star perhaps once in a million billion years

Accordingly this theory not only explains the existence of the planets but explains why they are likely to exist undisturbed for a very long period of time.

The mass of all the planets taken together constitutes less than one seventh of one per cent of the mass of the sun. This is in accordance with the theory, too, for the passing star would have pulled only a small part of the matter of the sun toward it. That it could have pulled out streamers at all is further made believable by the fact that the sun ordinarily sends streamers of gas outward from its surface for millions of miles, as may be seen during a solar eclipse. A streamer the length of which is equal to nearly half the distance from the earth to the moon is shown in Fig. 421.

A former popular theory — the nebular theory of Laplace — taught that the planets cooled from a hot mass of rotating gas extending outward beyond the farthest planet. Its supporters pointed to the fact that all the bodies of the solar system are revolving around the sun and rotating upon their axes in the same direction. It could not explain, however, why some of them are moving so much faster than others (why a little satellite of Mars, for instance, revolves three times about the planet while the planet rotates once upon its axis). Nor could it explain why the orbits of all these bodies are nearly but *nevertheless not quite* in the same plane. It finally collapsed when new telescopes showed that a satellite of Saturn and two satellites of Jupiter are revolving *backwards* (that is, opposite to the direction of motion of other moons) about their planets. These exceptions do not disagree with the planetesimal theory.

C. What lies beyond the Solar System?

Before the time of Galileo no one knew of stars other than those that could be seen with the naked eye. Of these there were about five thousand, and about a thousand could be seen from one position. In addition to the earth there were five known planets: Mercury, Venus, Mars, Jupiter, and Saturn. There were the sun and the moon, and there were also occasional comets and meteors.

About five thousand stars are visible to the naked eye

Today our good telescopes reveal millions upon millions of stars, and the bigger the telescope the more stars become visible. There are points of light that appear to the naked eye as single stars, but which prove to be double, triple, or quadruple when seen through a telescope. There are other stars that prove to be varying regularly in brightness, and there are cloudlike patches that reveal themselves as billions of individual stars, in groups far beyond the limits of the Milky Way.

Telescopes reveal many millions

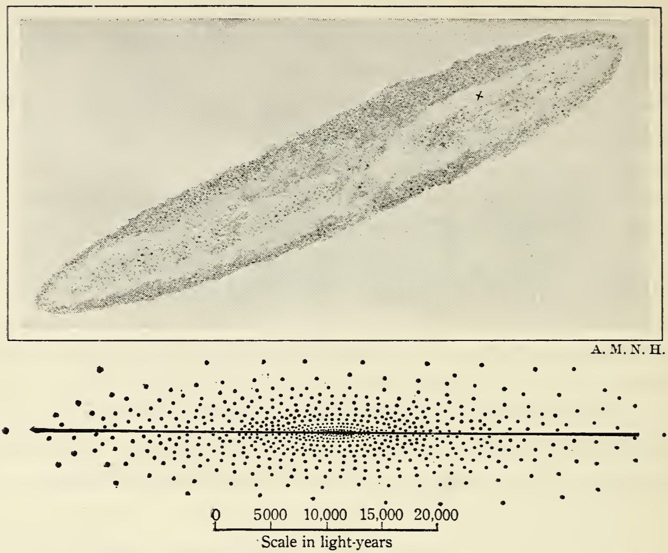


Fig. 422. The Sun is a Star in a Galaxy of Stars. As you look in the Direction of the Milky Way you are looking in the Direction of Greatest Diameter of the Galaxy

Why does the Milky Way appear as a white fog? [1]

One of Galileo's first observations was that the stars are not scattered evenly throughout all parts of the heavens. There are places where his telescope showed a thinning out in the numbers of fainter stars that may be seen. The larger telescopes show this even more clearly.

The stars are not scattered evenly throughout space

This phenomenon astronomers interpret as meaning that stars do not extend uniformly in all directions throughout space. It appears that the stars in our own system are scattered in a huge universe shaped somewhat like a watch. It is about one eighth as thick as it is wide. This is illustrated in Fig. 422. Can you imagine yourself looking outward into space

[1] From Sir James Jeans's *The Universe Around Us*. By permission, The Macmillan Company, publishers.

from within a vast group of stars shaped like this? As you look in the direction of its thickness, you see only a few stars. As you look in the direction of its breadth, there are many stars in the line of vision. There are so many that they appear as a great band of light, the Milky Way.

A constellation is a group of stars that appear to belong together, sometimes forming imaginary figures that look like animals, squares, or triangles. Spectroscope and telescope have revealed that in some cases these stars really do belong together, traveling through space in the same direction, while in other cases they appear to be together simply because they happen to be in nearly the same direction as seen from the earth.

You might think that some of the stars are fairly near to us. In space, distance is relative. The nearest known star (which is really a three-star system) is in the constellation known as the Centaur. It is more than four light-years distant, or about twenty-four trillion miles. Sirius, the next-nearest bright star and the brightest in the heavens, is about twice as far distant. The North Star is about four hundred light-years away, and Rigel, in Orion, is about five hundred light-years distant from the earth.

The nearest known star is more than four light-years distant

Each star that we see is really a sun — some very much larger than our sun, some smaller. They differ in color too. A blue star or a white star is very much hotter than a yellow star, and a yellow star is hotter than a red star — just as *red-hot*, when applied to a stove or molten metal, is not so hot as *white-hot*. The surface temperature on the sun is about 11,000° F. It is a yellow star, and other yellow stars are of about the same temperature.

Stars vary in size and temperature

The largest stars known are red and comparatively cool. Antares, in the Scorpion, is an example of such a star. It has a diameter four hundred and fifty times that of our sun. Betelgeuse, in Orion, is another red giant star.

The blue stars are smaller, but very much hotter. They average about twenty times the diameter of the sun. Vega is a hot blue star. The spectra of these stars show that their radiation comes chiefly from hydrogen and helium at a temperature of about 30,000° F. Other stars range in size and temperature down to small red stars, called red dwarfs, some no larger than the planet Jupiter. These red stars radiate comparatively little energy.

Recently two or three white dwarfs have been discovered, about the size of the earth, but greater in mass than the sun. The small companion of Sirius is one of them. Sirius is twenty-five hundred times as bright but only two and a half times as great in mass as the faint white dwarf.

There are also many cool "dark stars" in space. Does this seem like a contradiction in terms? Can there be stars that are cold and that give no light? We know that there are such stars, for in the cases of some of our double stars one star is light, while the other shows its presence only as it blots out the light of its brighter half. Others have revealed themselves by their gravitational pull upon their brilliant neighbors.

There are many double stars and star systems

Telescope and spectroscope show many double stars or systems of stars revolving about a common center of gravity. Sometimes the parts are widely enough separated so that they may be seen with the telescope. Often it is only the lines of their spectra that show the several parts. Sometimes the parts are about equal in size and brightness, but often they are not. There may be as much difference as there is between the sun and the planets.

The stars that appear to us brightest in the sky may be bright because they really are bright or because they are near. A street light, for instance, may be brighter than any star, simply because it is near. Sirius is an example of a near star. It is really of less than average size, but it is the brightest in all the heavens. When two stars at

equal distances are equally bright, there still may be a difference between them. One may be a red giant, comparatively cool. The other may be much smaller, but blue-hot. Their brightness, then, depends upon size and temperature as well as upon nearness.

D. What are Nebulæ?

In addition to the stars and star clusters, even a medium-sized telescope shows other objects that appear at first to be more or less misty, like great clouds of gas. They are called nebulæ.

A closer inspection and more careful study show that these nebulæ are of several different types. You doubtless know the constellation Orion, or the hunter, with his sparkling belt and sword. If you should look at this sword through a small telescope or even through a pair of field glasses, you would find a nebula surrounding the middle star, as shown in Fig. 423. This was thought until recently to be a gaseous mass, part glowing, part dark and cool. Analysis with the spectroscope seems to show it to be made up of solid particles like meteors — star dust, you might call it. This nebula

Yerkes Observatory

FIG. 423. The Nebula in the Constellation Orion, or the Hunter, seems to be made up of Solid Particles like Meteors

spreads through many millions of miles, but it is comparatively only a small affair and belongs to our own galaxy.

Nebulæ look like clouds

In the southern part of the heavens but beneath our horizon is a huge cloudlike mass called the Magellanic Cloud. Fig. 424 shows a photograph of it taken through a large telescope. This too is a nebula, but analysis shows that it is made up of millions of individual stars. It is far outside the limits of the universe with which we have been dealing up to the present and is apparently a universe in itself.

Yerkes Observatory

FIG. 424. The Magellanic Cloud shown here is a Nebula made up of Millions of Individual Stars

But there are other nebulæ, thousands of them, even larger than this Magellanic Cloud, probably as large as our own Milky Way, and each containing hundreds of millions of stars. Apparently in the constellation of Andromeda — although really far beyond it — is the nebula some nine hundred thousand light-years away from us. Yet our telescopes show that it too is composed of stars as widely separated from each other as the stars in our own universe. It is at least fifty thousand light-years in diameter, and about a tenth as thick. Do you suppose that it is a universe of stars

and that there may be planets moving about some of them? There is no reason to think today that such a question as this can ever be answered. Yet there may be evidences, coming through this far-reaching space, that would, if we could interpret them, furnish the answer to this question and many more. Man's curiosity leads him to continue unceasingly in his search for knowledge.

Spiral nebulæ are complete galaxies in themselves

E. What is Space Like?

The light that you might see tonight if you should gaze through a telescope at the Andromeda nebula is light that left those stars long before Neanderthal man lived in western Europe. Or to put it another way, you would not see the nebula of today but the nebula as it was nine hundred thousand years ago. "Looking backward into the past" is no empty phrase when applied to the heavens of modern astronomy.

Does space go on and on forever? No one knows. Even such authorities as Sir James Jeans, Albert Einstein, Harlow Shapley, and Forest R. Moulton do not agree. At any rate it goes on for millions of light-years. This space, though vast and dotted with stars, — yes, even with galaxies and possibly super-galaxies, — is really more nearly empty than the best earthly vacuum.

Space and time are vast

What becomes of the energy that is given off continuously by all these billions upon billions of suns? Is it lost forever unless it happens to reach another object in its path? Is it in some way changed into matter, as matter is now known to be changed into energy? We do not know.

Astronomers have gone far in answering our questions, but much remains in the unknown. Man seems small upon this small earth after even this short excursion into space.

But does it not seem remarkable that he has so far conquered the tools of his environment that he is able to reach out into space and time upon a journey such as this?

Our most probable modern theory supposes that the planets were pulled out from the mass of the sun as a second star came close to it. This happened billions of years ago, and such another event is not likely to take place for many billions of years more. Our solar system is only one very small part of the galaxy which includes the Milky Way and all the bright stars visible to us. But this galaxy is only one of thousands that lie beyond us in space. One neighboring galaxy, the spiral nebula in Andromeda, is some nine hundred thousand light-years distant. Man has gone a long way toward understanding this vast universe, but he still has a long way left to go.

Can You Answer these Questions?

1. What is the probable source of the earth's atmosphere?

2. What is the planetesimal theory of the formation of the earth? What is the tidal theory?

3. According to these theories was the earth ever smaller than it is today? How is this explained?

4. What facts are there which help to support these theories?

5. Why was the nebular hypothesis of Laplace abandoned?

6. Can you explain differences in meaning between *earth, solar system, galaxy,* and *universe*?

7. What evidence is there that stars do not extend uniformly in all directions throughout space?

8. What factors determine the brightness of a star?

9. What are nebulæ?

10. Why is it probable that the planets will not be disturbed by near approach to a star for a long period of time?

11. Compare the Magellanic Clouds and the Milky Way.

Questions for Discussion

1. Is man's knowledge of the universe beyond the solar system of any practical use to him?

2. What do we mean by *infinite*?

3. Is the earth becoming larger or smaller as time goes on?

4. Is it possible that there may be other worlds similar to our own far out in space? If there are such worlds, should you expect that they are composed of the same chemical elements as compose the earth? Explain.

Here are Some Things You May Want to Do

1. Make a study of earlier theories and myths about the origin of the earth. Which ones have been completely denied and which have been modified? Were any points of the planetesimal theory contained in any earlier theories?

2. Prepare a series of diagrams which would illustrate the formation of the earth according to the planetesimal theory.

3. Several years ago the staff of the Harvard Observatory gave a number of radio talks on astronomy. These were later published under the title *Universe of Stars*. These lectures are not difficult to read. Another simple book which deals with the content of this chapter is Hale's *The New Heavens*.

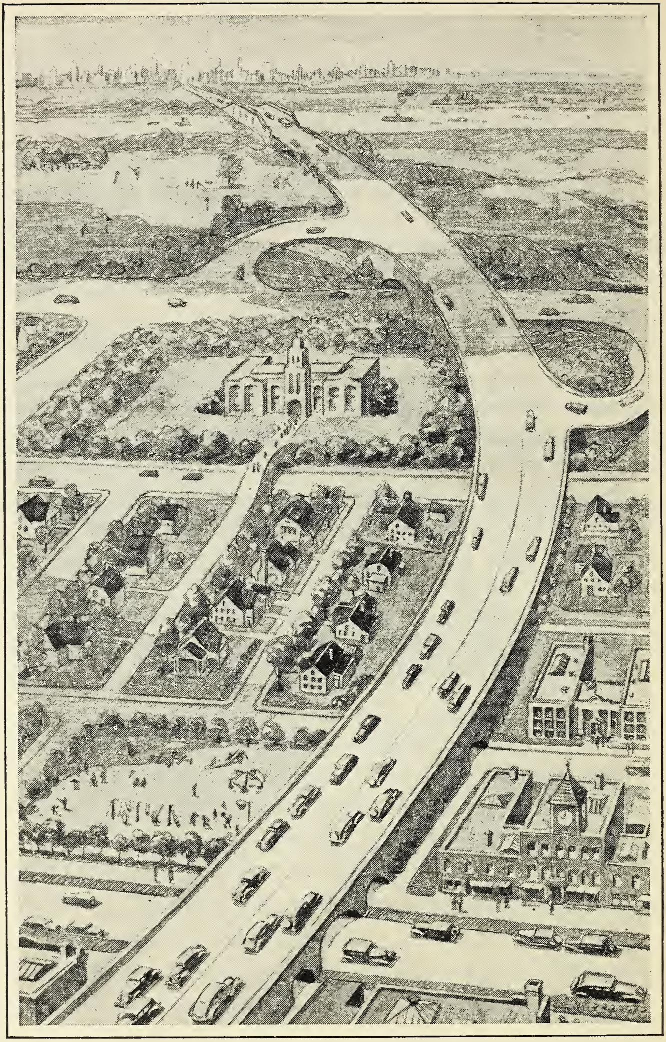


Fig. 425. The City and Country in the Future will be far More Closely Related

UNIT VIII

Is Man controlling his Environment in the Best Possible Way?

Chapter XXXIII · Is Man making the Best Use of his Knowledge of Science?

AS YOU have studied this science book during the year, you possibly have noticed a number of times that its title is *Man's Control of his Environment.* It is one of a series of three books called A Survey of Science. Throughout the three books we have given you information, and suggested ways in which you could find information for yourself, regarding the contributions that science has made to modern living.

This survey has shown that in hundreds of instances science has contributed to the betterment of mankind. The kind of water we drink and of food we eat and of clothes we wear has in most instances been made possible through the findings of science. The health we enjoy, the trains, airplanes, and automobiles in which we ride, the radios to which we listen, have been produced through what man has learned from science. You could name in a very few minutes over a hundred things that have contributed to your own welfare and happiness and for which you are indebted to the findings of science. In fact, the progress we have made in applying what we have learned regarding science has been so great that most of us have given little thought to the question of whether or not we have made the greatest possible use of our knowledge.

Have we applied our scientific knowledge of health and health conditions in such a way that we have relieved as much illness as we could? Have we produced, transported, and made available enough food for everyone in the world? Do we know enough about science to make these kinds of things possible?

In this book, as well as in the two others of the series, you have been surveying what the findings of science have done for mankind. We are going to survey briefly with you now what science could and should do for mankind.

Chapter XXXIII · Is Man making the Best Use of his Knowledge of Science?

The subject of science in our schools has had an interesting history. If you had attended school in 1830, you would not have found science as a subject in the schools, but would have found it included under "natural philosophy." In 1836 Boston introduced into the schools as an experiment "a certain portion of philosophical apparatus." This apparatus was confined to pneumatics (a subject which treats of the mechanical properties of gases) and electricity. In 1847 apparatus of somewhat superior construction and embracing a much wider field was introduced. Mr. Richard Green Parker prepared a manual, called Parker's *Philosophy,* to accompany the first apparatus. This manual was revised several times and was used as the textbook in science for the schools of Boston. If you were to examine it along with other books in natural science written from 1800 to 1880, you would find a number of interesting things.

In the first place, you would notice that in certain parts of some fields these early scientists knew almost as much about science as we do today and made use of many of the same experiments that you have become acquainted with or performed in your work in science during the last three years. For instance, they used, of course, the experiments of Torricelli and measured air pressure with a column of mercury. They also included many of the experiments regarding simple levers that you have employed in certain parts of your work. In other fields, however, — for instance, electricity, — the differences are striking. In an old book, *Lectures on Chemistry,* written in 1831 by W. G. Hannaford, we find the following about electricity:

. . . By Franklin's discovery, i.e. that it was the same as lightning, we might say that it was, to a certain extent, rendered

harmless to mankind; but it would appear, that another Franklinean discovery was necessary, in order to render it of much use.

In this subject, we have one different from almost any other, with which we have anything to do, either in this science, or experimental philosophy. Such is the fact, that almost all the principles, in the experimental sciences, can be so satisfactorily illustrated, as to leave no doubt in regard to their correctness. Not so with this; it is extremely difficult by any direct experiments, to prove what it is, or much in regard to its properties. This being the case, there have been very many different theories upon this subject; some considering it a simple substance; others supposing that there are two fluids, called vitreous and resinous; others that it is merely a property of matter. To explain all these different theories, would require much time. I shall, therefore, entirely omit it; but shall select that *theory*, which is usually adopted in this country, and which appears to have as much evidence in favour of its being correct, as any; and explain the principles of the science, and the few experiments to which we may be able to refer, according to this theory. It has at least some things to recommend it; for upon this theory, the principles of the science are more simple, more easily explained and applied to useful purposes, than perhaps any other.

The theory to which I refer, is generally called the Franklinean theory. Not because it was first adopted by our own . . . . .

The remainder of the entire lecture on electricity in this book is devoted to simple experiments to illustrate the proposition that "bodies similarly electrified repel each other and when dissimilarly electrified attract each other," and closes with a discussion of the lightning rod. Thus we see that although in static electricity some of the simple experiments were the same, we naturally find no references to the thousands of things that have been discovered in recent years about electricity and its application. Some of these, of course, were included in later books as the discoveries were made.

The second thing you would notice would be statements of numerous principles and definitions. For example, in Mr. Parker's book referred to above you would find the following:

10. Galvanism is a branch of Electricity.

11. Magnetism treats of the properties and effects of the magnet, or loadstone.

12. Electro-Magnetism treats of Magnetism induced by Electricity.

13. Magneto-Electricity treats of Electricity induced by Magnetism.

CHAPTER II.

OF MATTER * AND ITS PROPERTIES.

3. Matter is the general name of every thing that occupies space, or has figure, form, or extension.

* The ancient philosophers supposed that all material substances were composed of Fire, Air, Earth, and Water, and these four substances were called the four elements, because they were supposed to be the simple substances of which all things were composed. Modern science has proved that not one of these is a simple substance, but that there are at least fifty-five simple substances, thirty-two of which are metallic and twenty-four non-metallic. The consideration of those substances which enter into the composition of all matter, in whatever form, belongs to the science of Chemistry. Bodies which consist of one simple substance are called *homogeneous*, while those which consist of two or more simple substances are called *heterogeneous*. Thus, water is a heterogeneous substance, being composed of two simple or homogeneous aeriform fluids, called Hydrogen and Oxygen. An aeriform fluid is a fluid in the form of air. When the particles of which matter is composed is mentioned, it is to be understood that the smallest imaginable portion is meant, not of the homogeneous substances of which it may be composed, but of the matter itself, whether homogeneous or heterogeneous.

4. There are seven essential properties belonging to all matter, namely: 1. Impenetrability, 2. Extension, 3. Figure, 4. Divisibility, 5. Indestructibility, 6. Inertia, and 7. Attraction.

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3. What is Matter?

4. How many essential properties of matter are there? What are they? Why are they called essential properties? What . . . .

The third thing you would observe would be the type of questions you as a student would have been supposed to answer in case you had taken science during those years. In the main the questions would have required that you learn these definitions and principles word for word. For

example, in Mr. Parker's book the questions on the subject matter quoted above were as follows:

DIVISIONS OF THE SUBJECT.

ART. 1.—What is Natural Philosophy?

ART. 2.—What are the principal branches of Natural Philosophy? What is Mechanics? Of what does Pneumatics treat? Of what does Hydrostatics treat? Hydraulics? Acoustics? Pyronomics? Optics? Astronomy? Electricity? Of what is Galvanism a branch? Of what does Magnetism treat? Electro-Magnetism? Magneto-Electricity?

OF MATTER AND ITS PROPERTIES.

ART. 3.—What is Matter?

ART. 4.—How many essential properties of matter are there? What are they? Why are they called essential properties? What other properties exist in different bodies? Why are they called accidental properties? Are color and weight essential or accidental properties? Why? What terms are used in Philosophy to express the state in which matter exists? What follows from this?

The first great stage through which science passed in the public schools, then, might be called the stage of learning principles and definitions. The general practice seemed to be to have the pupil commit to memory most of these principles and definitions and recite them to the teacher without the aid of any book or any notes.

An early stage of science-learning in America was the learning of scientific principles and definitions

Although even in the earlier years certain principles were illustrated by simple experiments in the few schools which could afford any kind of apparatus, it was not until the twentieth century that wide application of these principles was made to practical things in life. This tendency to make applications, in the work in science in the schools, to such things as the operation of steam engines, electrically driven trains, and airplanes followed

of course the discovery of such applications in the actual work outside the schools. When one considers the hundreds of advances made in the last fifty years, including sanitation, the radio, television, and transportation, to mention only a few, it is not difficult to understand why the teaching of science in the schools began to change.

The second stage might be called the application of principles. We have not, of course, determined all the principles of science. In addition, we certainly have not begun to explore the possibilities of the application of those principles we do know. Unfortunately in most of our schools we are not making as great use of the practical-application side of science as we should. We have been too content to take our work from books only or from simple experiments in the laboratory, being blind to the numerous possibilities found in almost every community for the study of the wonders of science in their application. In almost every community in this land motors and dynamos, steam engines and turbines, airplanes and factories, power plants and hospitals, broadcasting stations and telephone exchanges, beckon us with innumerable opportunities to study the principles of science in their practical application. Views from the windows of two schools appear in Fig. 426. Do you think they suggest possibilities for practical study?

The second stage dealt with the application of principles

The third stage of learning and teaching science we are just beginning to enter. A most important feature in this third stage might be called science in its social applications, or science for the greatest betterment of mankind. Up to date most of our study of the applications of the principles of science has been made in order to help us to understand how these principles operate, for example, in driving a train, in sending a message, or in preventing illness. The new stage that science is approaching will go far beyond the mechanical or the method side of science and will ask

The third stage deals with the social use we are making of science

Ewing Galloway

Fig. 426. In Almost Every Community there are Innumerable Opportunities to study Principles of Science in their Practical Application

Are there more opportunities in the city (above) than in the country (below)?

such questions as Of what real use is this application to men? Is it of the greatest use for everybody? Have we made science serve all of us in the best possible way? Are all of us as healthy as science could make us? Does every person enjoy all the blessings and conveniences that would be possible if the best we know of science were fully applied? Are men making the best possible use of the machines science has produced?

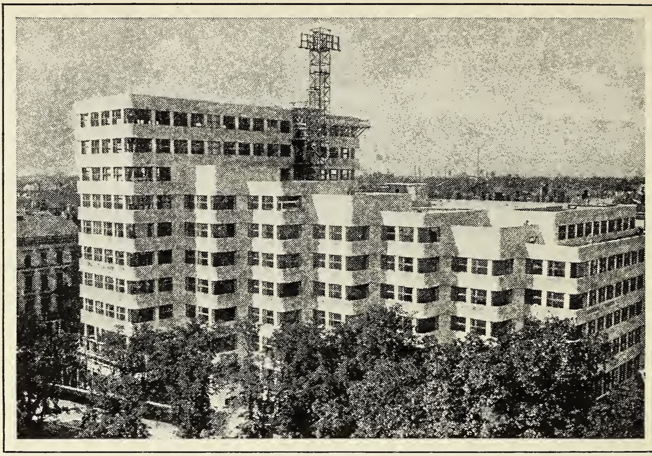
May we indicate through an illustration centering around the last question some of the kinds of things which all of us will have to think about in connection with the social ap-

plications of science? A few months ago a visit was made to a class in a public school of one of our cities. The pupils in this class had been studying the different industries of their city. During the preceding week they had divided into groups and had visited a number of different factories and plants. Three of them had visited an oil-cracking plant; four had spent a large part of a day at a tannery; three had studied a newspaper plant; five had been to machine shops; seven or eight had visited various industries concerned with building and road-making; and the others in groups of from three to five had visited other kinds of industries.

On this particular morning the different groups were discussing the kinds of machines they had seen, the uses to which these machines had been put, and the products they were turning out. One of the boys, who had been visiting some building-construction plants, had also attended the Century of Progress at Chicago. One of the other members of the class, as well as the teacher, had also visited the new housing exhibits at the fair in Chicago. The visitor to the class that morning had been studying recently some new types of houses that were being planned not only in the United States but in certain parts of Europe as well. One is shown in Fig. 427.

These four, with the aid of suggestions from other members of the class, described the types of houses everyone might have if proper use were made of the things science has taught us about building. They showed that our machines could turn out for us beautiful, durable houses made of steel and glass. In these houses there could be uniform lighting, so that every part of a room would be lighted to the same degree. This would mean, of course, that there would be no glare on the page of the book a person was reading. Neither would there be any straining of the eyes because of too little light. It

A complete application of known scientific principles would greatly change our housing conditions



Keystone

Fig. 427. New Apartment Houses make New Applications of Old Materials

Do you see any new applications of steel, concrete, and glass?

might even be possible to change the color scheme in any of the rooms merely by pushing a button. These houses could have conditioned air the year round — the kind of air that would be pure and constantly at a temperature which would be comfortable and healthful. One of the boys in the class remarked, "How stupid the people of 1950 will probably think we are, to have lived in poorly heated and poorly ventilated houses!" It was brought out in the discussion that these houses could be so arranged that many of the partitions between the rooms could be raised by merely pushing a button, thus enabling the family to open up a large space for games or teas or receptions. By making proper use of machinery these houses could be constructed very rapidly, since they could be made of large sheets of glass or metal which the factories could turn out by the thousands. These sheets could then be shipped and fitted together in very little time into houses of all sorts of designs.

Some of the members of the class, after they had heard

this part of the discussion and had seen pictures of some of the new types of housing, compared this method with the methods used for the most part in their own city. One girl remarked, "Think how slow and clumsy it is for carpenters to put on one board at a time when we could have this kind of construction."

The discussion turned again to the kinds of houses that would make air-conditioning possible. While these pupils did not consider the many different factors at such length as you did when you studied Chapter XXVII, they did find out that a different type of construction would be necessary. The teacher told them that, in one of the air-conditioned houses which she saw, a new type of material was used on the walls and ceilings; that this material which science has made possible was of great assistance in keeping air at proper temperature, and that it could be turned out in large sheets and could be put on very quickly. At this point one boy wanted to know what would become of our men who lath, plaster, and paper walls if this kind of material were manufactured by machines and then used. What would happen, also, to our carpenters and shinglers and other people engaged in the building trades as we now know them?

Several pupils in the class expressed the opinion that we should not allow our machines to take the place of men in this fashion. These pupils spoke feelingly, for at this particular time at least two thirds of their fathers were on government relief or employed in government-made work.

Similar applications might change greatly the work people do

Here the discussion changed abruptly from new kinds of construction and housing to a question that seemed much more important; namely, Shall we let these machines which science is making possible throw our fathers out of work? Those who had visited the post office told how the stamping machine there had replaced a number of people. Others who had visited the cotton gins told

Ewing Galloway

Fig. 428. Do Human Beings have to do such Work as This?
This photograph was taken in a tannery

the same story. Illustrations multiplied. One of the boys suggested that new kinds of jobs would be created in the new types of construction. The teacher told them some of the things that happened when the automobile was invented. She reminded them that at the time some people had spoken of how hundreds of workmen in the carriage and wagon factories would be thrown out of jobs. After we began making automobiles, however, thousands more were employed in assembling parts, selling gasoline, and constructing new highways for automobiles than had ever been employed in the carriage and wagon factories.

"But what if we invent machines that can do all our work?" asked one girl.

"But we don't want machines to do all our work," replied another.

"What kinds of work do we want our machines to do?" was the next question.

At this point the teacher called the class to the windows of the room. It was a dismal, rainy day. A cold mist was falling, and the ground was soaked from a heavy rain of the previous night. Across the yard of the school a number of men, some of them the fathers of these pupils, were digging a ditch for a sewer. The teacher asked whether they saw anything that bore on the question that had been raised. Finally one of the girls in the class said that men ought not to have to labor in the mud, and that machines should do this kind of work. Immediately one of the boys exclaimed, "And there is a ditch-digging machine only a few blocks away from here, and it's standing idle!"

"But father is so glad he has a job. So is mother, and so are all of us. He was without one for so long," said another.

The discussion grew so interesting and the suggestions seemed to the visitor to be so excellent that he took some of them down and gave them to one of his friends, who wrote them up. They appear below in almost the same words the pupils used.

Machines and People

If we are wise we can learn how to use our machines to make us live better and to be more comfortable.

Machines should be our iron slaves. They should work for us, help us, protect us. Can we make them do this?

What kinds of work should we have our iron slaves do? They should do all work that is too hard for men and women. They should do work that has to be done very carefully. They should do work that is unpleasant and work that is dangerous. They should do the work that has to be done very rapidly.

It is hard work to lift great weights. Let the machines do it. They have no backs to break. It is unpleasant work to care for garbage. Let the machines do it. They do not mind ill-smelling odors. It is dangerous work to pour white-hot metals. Let the machines do it. They have

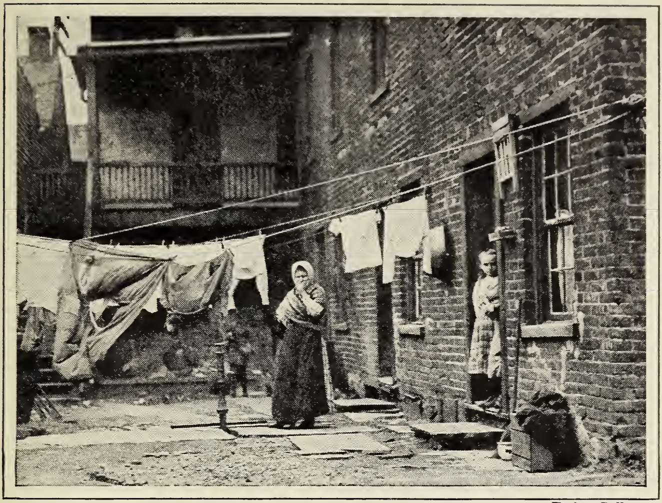
no hands to burn. It is careful work to make tiny watch springs. Let the machines do it. They have no eyes to ruin. It is fast work to print a daily newspaper. Let the machines do it. They do not mind hurry and confusion.

There are thousands of jobs for the machines which men and women do not want to do. Many of these are jobs they should never have to do. When we have learned to use our machines wisely, we shall never have to do such things.

But men and women enjoy doing many kinds of work. Indeed, people would be quite unhappy if they did not have a chance to do their work. Machines should not be used for work of this kind. In fact, much of such work cannot be done by machines. We do not want machines to paint our pictures. We do not want machines to take our trips. Some people do not want them to work in the garden for us. Some do not want them to carve our toys and ornaments. Some do not want them to make our music, or even cook our meals, or run our trains. Some are glad that machines cannot do these things as well as men and women can. If they could there might be a time when there would be no work left for us to do.

But there is work for both machines and people. There are many new kinds of work we have never done because we have not had the time to do them or they cost too much. We need more houses for people to live in. We need more doctors to care for all of our sick people. We need more teachers to show the people better ways of living. We need workers who can change poor farm land into growing forests. We need engineers to drain swamps and water the dry deserts. We need to do thousands of things we have not had time to do before. With the help of our iron slaves we can do these things.

We see, then, that science cannot be thought of alone. It must be considered in relation to what it can do for mankind. Although there are a few who like learning for



Ewing Galloway

FIG. 429. Are such Housing Conditions Necessary?

learning's sake, people as a general rule wish to put their learning to work for the good of themselves and others.

Let us explore a little further what might be possible in the case of some of our large cities, provided most of the findings of science were made use of. There are hundreds of thousands of people housed in old tenements. Thousands of people are living in apartments so dark that gas lights must be burned all day. In some of these apartments there is no light whatever. Others are so airless that in summer tens of thousands of people are forced to sleep in the parks or on the roofs. Others are so foul-smelling, because of garbage in the streets, the small courts, and the hallways or because of near-by stables and factories, that the one or two windows in the whole flat have to be kept shut. There is neglected plumbing as well as insufficient water. In some of these apartments as many as ten to eighteen people live in three rooms. And not all of the

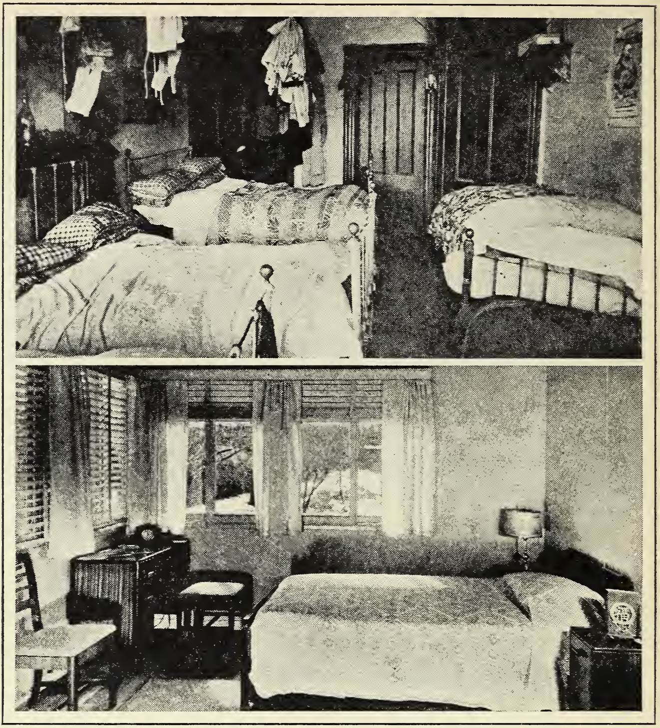


Fig. 430. Which of these Bedrooms do you think offers Better Opportunities for Healthful Sleeping?

Why does anyone have to sleep in a place like the upper picture?

poor housing conditions are to be found in New York and other large cities. Most of you will not have to go many miles from your own homes, whether you live in rural areas or city areas, to find people living under extremely undesirable conditions. Some of our most unsanitary and unclean dwellings can be found in rural areas. What a tragedy that such conditions should exist when science has shown us the way to remedy them, provided we were wise enough to make plans by which the products of science

could be used. Think of hundreds of thousands of people living in the slums of the city when we have in the United States fifty-seven acres of land for every person!

But, you may say, our people must be near their work. This too we could make provision for in rebuilding our most densely populated areas. What are some of the things we could do? Instead of building all our factories in overcrowded centers we could, if we would, build many of them several miles from the heart of our cities. The workers then could live on an acre or more of land and enjoy the pleasure of green pastures, trees, and running brooks. They could be housed under most sanitary and convenient conditions and still be near their work. Why shouldn't, for instance, their kitchens be completely equipped with every electrical tool that would save human drudgery? Why shouldn't their factories as well as their homes be constructed so as to provide for the very best that science knows in the way of comfort and efficiency?

In some cases, because of the type of product which is being turned out, it might be necessary to mass factories and offices in certain large centers. If this were the case, why shouldn't we call on science again and produce large numbers of garden cities located ten, twenty, and thirty miles from the factories themselves? There are a number of such garden cities in America, England, Germany, and elsewhere today. Many more will probably be built.

The ideal garden city would not be built on the rectangular-block idea. Beauty would be combined with safety and efficiency. The streets and the homes would be adapted to the shape of the land on which they were built. The houses would be constructed with a high degree of attractiveness, and each home would fit into the picture of the whole community. They would face each other across large green parks and playgrounds. From the back of each house would be a small road connected with the through highways on the outskirts of the community.

In no case would a child going to school have to cross any road used by an automobile. Trees and shrubs, flowers and green grass, would be grown at the places where they would be most lovely and effective. In the center of the community would be located the schools, churches, and community buildings used by all the people. The stores and commercial buildings would be located at convenient places in the outlying sections of the community.

The large through highways would pass on the outskirts and never run through the community itself. No cross traffic would be allowed. The highways would be built over and under all cross traffic, and would be so built that they would stand up for years under fast traffic. The lanes would be broad and straight; automobiles would be fashioned so expertly that they could carry their passengers a distance of twenty miles in from ten to twenty minutes. Science can easily give us such a machine. The trains would be built of composition materials similar to the type which you studied in Chapter XII and would race safely at a speed which would bring the resident of the garden community forty miles out to his work in the city in much shorter time than many a person can now reach his work by street car or bus. When, in the not distant future, private airplanes can be produced and sold so cheaply that they can be purchased and operated safely by large numbers of our population, provisions will be made, of course, for landing in central places in the city and in our own back yards in the garden communities.

Some of these days, too, man may learn to make such effective use of the machines which science will give him that all people will have the opportunity to do some of the things they like best, in addition to the work at which they are professionally or vocationally engaged. There will not only be more time to play but more opportunity to give fresh thought to those things in which each person is most interested. Under such a scheme the chances seem to be

rather large that we should have more inventions than we have had in the past, more beautiful music and art, and more lovely things constructed by hand — in fact, more human happiness.

If such an ideal world is to be approached or reached, science and sociology (the study of society) must walk hand in hand. We must try to make every new finding in science serve humanity to the utmost.

You may ask yourself what you can do in this respect. The experience of a senior class in a certain high school in one of our cities may help you in your thinking. This class had been discussing explorations, the pushing back of frontiers, and the opening up of new areas. In the midst of the discussion the instructor asked what the most promising areas for exploration are at the present time. Several answers came rather readily. One student said that he would like to explore the upper parts of the Amazon River; another, the interior of Africa; a third, the antarctic and arctic regions. But the teacher continued with his question, "Are these the areas which if explored today would result in the greatest good for the world?" Finally one boy suggested exploration in the fields of science, and a girl the finding of new things in the field of art.

As a result of this discussion the students came to the conclusion that although decided and in some cases unusual progress has been made in science, art, music, and many other areas, there are still thousands of things left for those of the coming generation to do. Not only are there new things to be discovered, but nearly everything needs to be done over in a better way. Nothing is good enough. The fastest and safest airplane has not been built; the softest and most effective light has not been manufactured; the tastiest and most healthful foods have not been produced; the certain cures for many diseases have not been found. The very progress we have made seems to have resulted in more things which need to be done.

Fairchild Aërial Surveys, Inc.

Fig. 431. This Modern Garden Community offers Far More Opportunities for Healthful and Pleasurable Living than does the Average Community

What evidence of this can you see?

Some things have been done well, but with many things blunders have been made. The chief mistakes seem to have been in the field of making the best use of the sometimes marvelous results given us by science. It is to this area, then, that we hope you will turn your attention in your future work with science, for in it lie the greatest opportunities and challenges for improving both yourself and others.

Science learning and teaching has had three stages: first, the learning of principles and definitions; second, the application of principles; and third, the social use made of science. The development of the third stage has just begun. As the application of the principles of science becomes more and more a part of community life, great changes may be expected in man's ways of living and working.

Questions for Discussion

1. How should you like to have to learn pages of your textbooks word for word? Do you think the method a good way to learn new things? What methods of learning have you used in your science work this year?

2. What is the "scientific method"?

3. Is all your knowledge of science gained in the classroom? Do you use in your life outside of school any of the science you learn in school? Make a list of the different ways in which you have used your community in your study of science this year. Make a second list which will include additional possibilities that your community offers for the study of science.

4. What things do you lack that science is ready to give to you?

Here are Some Things You May Want to Do

1. Make a list of the things which you feel science should and could do for all the people of your community. Give reasons why these things have not been done. Make suggestions for remedying this situation.

2. As a class project draw up a plan for your community which would make use of every desirable thing science could supply. The project might be entitled "Our Community in 1975." Use your thought and your imagination in showing the numerous great improvements that could be made. Some of you may want to work on improvements possible in transportation, while others would take such topics as improvements in health, communication, and recreation facilities. Why not make a plan of your community as it would appear in 1975 and also a large illustrated booklet covering every type of suggested improvement? They could be presented to your city council or to those in charge of community betterment. You may even want to stage a pageant in which you picture your community of the future.

A SUMMARY VIEW OF *MAN'S CONTROL OF HIS ENVIRONMENT*

IN YOUR study of *The World Around Us* you learned of plants and animals adapted to live with one another in a physical environment. There is great variety in the physical conditions, and there is great variety in the character of the living things that are adapted to the different conditions. In all environments the necessities of life are taken from water, air, and soil; and the energy for the vital processes is abundantly supplied from the sun. In the cycles of life, living things must depend on other living things. Only green plants can store in foods the energy of solar radiation, so energy for life and growth must flow from the sun to all living cells by way of green plants.

Energy of solar radiation, together with the force of gravitation, keeps things moving over the surface of this changing world. There is a cycle of air flowing over the surface of the earth as the force of gravity causes the colder and denser air of the polar regions to move toward and to take the place of the less dense air of the equatorial regions. There is a regular movement of water in the oceans as the force of gravity causes the colder and denser water of the north and the south to move slowly toward the equator. There is the water cycle, in which radiant energy causes water to evaporate and to be carried over the land, where it may lose some of its molecular energy, fall as rain, and in time flow back to the sea. Under the influence of these forces the surface of the earth is continually changing. Then, too, there is the flow of matter and energy from nonliving to living things. Nonliving matter is built into protoplasm, and the matter of which protoplasm is composed becomes again nonliving matter. As we survey this complex environment, nothing seems to be fixed. Everything seems to be in the process of change. Organisms adapted to live in this changing world seem to struggle

with each other for the matter and energy that are necessary for life and growth.

Among the organisms of this changing world the human organism stands at the top. You see evidence of this position of power as you study *Man's Control of his Environment.* This ability to control is a feature that distinguishes man from all other organisms. The history of the human race is a story of progress in control, beginning with extremely simple controls and continuing through the successive culture periods to the complex civilization of this Age of Iron and Power in which we live today. Progress in control seems to have been a continuous struggle in which man, through the use of his intellect, has acquired understanding of the material substances of which the earth is composed and of the energy which flows over its surface, and has used this understanding to make his position in the struggle for existence more secure. Through the exercise of his intellect he has learned to use for his own advantage the matter and energy of living and nonliving things.

Through control of living things and of the conditions under which they grow, man has learned to produce a food supply for a constantly increasing population. Cultivated plants have been selected from food plants that once grew wild. Through exercise of intelligence the quantity of food produced from these plants has been enormously increased. It seems perfectly certain that the quantity of production may still be greatly enlarged. The average yield of corn, for example, in the United States is about 27 bushels an acre. The yield of wheat is about 15 bushels an acre. The quantity of production per acre of both these important grains could probably be doubled if such production were necessary.

Similarly, domesticated animals have been selected from animals that were once wild. Animals have been bred and used as beasts of burden as well as for food. In this Age of Power there is but little use for animals except as they are used for food. In America the chief food-producing animal

is the cow. Through exercise of intelligence in breeding, the quantity of dairy products as well as the quantity of beef has been increased, and at the same time the quality of these products has been improved. The average production of milk by dairy cows in the United States is about 700 gallons a year per cow. Individual cows have produced as much as 4000 gallons in one year. Certainly the quantity of milk production could be enormously increased if all that is known about milk production were intelligently applied. Increase could be accomplished through increasing the number of milk-producing cows and by increasing the amount of production from each cow. As we consider man's achievements in production of food, we are led to decide that the quantity of food supply could be increased enormously if such increase were necessary.

Accompanying the growth of knowledge from which there has come an ability to control the food supply, there has been a growth in knowledge of how to use materials. Primitive man was limited in materials for tools to wood, bone, and stone. With advances in knowledge man learned to use metals. Now it is possible to make alloys, glass, building stone, and other materials almost at will to fit the demands that are made upon them. Some metallic ores are being exhausted, but it seems certain that alloys of other metals will be made to take the place of those that are difficult to obtain. The crust of the earth is the source of such materials, and there is an abundance for every imaginable need.

A third achievement of the human mind is the acquiring of control over energy from natural resources. Throughout the whole period of man's existence on earth, there has been an abundance of coal and oil in the crust of the earth, and through all this period water has flowed in streams from higher to lower levels. Yet it is only during the past one hundred years that man's achievements in control of energy have, in a large way, influenced the character of civilization. Throughout most of the history of the human race, energy

for the work of the world has flowed through the muscles of men and beasts of burden. With energy from this source there were definite limits to what men could do. Before the days of George Stephenson there could be no express trains, for no number of horses and men could move a train of cars weighing 1000 tons with a speed of 60 miles an hour. Before the days of Thomas Edison there could be no electric lighting, for there was no known way of changing electrical energy into light. As a result of achievements in control of energy the possibilities for accomplishment have been enlarged enormously. The means are at hand with which men may be freed, in large measure, from the necessity of drudgery. Energy from natural resources flowing through the wheels of machinery may be used to do the physical labor, and men may be permitted to use their efforts in ways more satisfying to them. There seems to be no practical limit to the quantity of energy that may be released from natural resources. Most of the present supply comes from coal and oil. There is an abundance of these fuels, and we could without doubt use them with much greater efficiency than they are now used. In addition to these fuels there is a continuous supply of energy coming from the sun. It seems as if man may, by the proper exercise of his intelligence, cause energy under control to flow over the surface of the earth almost as freely as do air and water.

Along with his control of matter and energy man is increasingly gaining control of himself—in the sense that he is able to maintain more effectively his bodily vigor and protect himself from contagious disease. Many of the major causes of ill health are now well understood and effectively controlled. The science of sanitation has shown us how to protect crowded cities from contagious disease, which, if uncontrolled, would be terribly destructive. The science of nutrition has taught us to select foods in accordance with the needs of the body. In these and in other particulars the achievements in the elevation of health standards seem impressive.

The practical achievements in control of nonliving matter and energy and in control of living things, including the causes of ill health, have contributed in a large measure to man's feeling of security, and they have enlarged enormously the possible range of his activities.

Along with these practical achievements man has gained an enlarged understanding of himself as a biological organism, and he has greatly extended his knowledge of the phenomena of nature. Evidence of intellectual achievements is seen in the ability of individuals to interpret common observations. It is without doubt true that we are influenced in our thinking by our ability to understand the nature of things. As a result of study in science, progress has been made in freeing the human mind from such errors in understanding as those associated with belief in astrology, alchemy, witchcraft, magic, and other forms of superstition. This progress has come as man has gained understanding of himself and of his environment. Larger gains may be expected as man finds leisure to exercise his intelligence.

What of the future? Progress in the development of understanding and in ability to use this understanding has come rapidly. Practically, scientific study may be thought of as having its beginning with the work of Galileo, some three hundred years ago. From then until now its influence has been rapidly extended. Changes have come so fast that adjustments within the social order have not kept up with them. It is entirely likely that scientific study will continue to produce more and more rapid changes in our society. Nearly all the developments in control of energy, for example, have come during the past one hundred years, and by far the largest part of this control has come during the past thirty years. With such progress as has been made in control of energy and in control of those living things from which we get our food supply we can, as you have seen, produce more of the necessities of life than can be used, and at the same time we can allow an abundance of leisure. The extent of these controls

will certainly be enlarged. This is on the side of production. But means for distribution have not kept up with production, for with overproduction of the things that make for comfort there is at this time a large proportion of our population suffering for want of food, clothing, and shelter. It seems certain that this unfortunate condition is owing, in part, to lack of understanding of the extent of man's achievements.

In summary, you have learned from your study of A Survey of Science something of the achievements of science and something of the possibilities that lie in the future. There is at hand, as you have learned, a body of knowledge about control of energy, control of ill health, weather phenomena, heredity, natural and artificial selection, changes on the surface of the earth, space, time, life processes, chemical changes, gravitation, machinery, the nature of matter, and many other things. It is from this knowledge that there have come the possibilities for gaining health and leisure and the possibilities for further enrichment of living. The achievements of the past serve to forecast, in a measure, the achievements of the future. To you who read this book, it may be said that no generation before you has been permitted the richness of experience that may be yours. At the same time it should be seen that in no other generation has the well-being of society as a whole depended so much on intelligent effort of all the individuals that make it up. The extent of your success as a worker in society will be fixed, in large part, by your ability to interpret the conditions that have produced it. Outstanding among the factors that have determined the character of our society are the achievements in control of energy, in control of the living things from which we get our food supply, in control of the causes of ill health, and in understanding of ourselves and of the natural phenomena with which we are surrounded. In your study of A Survey of Science you have laid a good foundation for that richer understanding which will come as you extend your study in the senior high school and in college.

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A well-organized text which high-school pupils can use.

BAKER, ROBERT H. When the Stars Come Out. The Viking Press, New York, 1934.

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BAYNE-JONES, STANHOPE. Man and Microbes. The Williams & Wilkins Company, Baltimore, 1932.

Discusses microbes in connection with soil, air, water, sewage, industry, plants, insects, diseases of animals, and diseases of man.

BOCK, GEORGE E. What Makes the Wheels Go Round. The Macmillan Company, New York, 1931.

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CALDWELL, OTIS W., and LUNDEEN, G. E. Do You Believe It? Doubleday, Doran and Company, Inc., Garden City, New York, 1934.

A discussion of many current superstitions.

CHEESEMAN, EVELYN. The Growth of Living Things. Robert M. McBride & Company, New York, 1932.

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COBURN, WALTER E. High School Electricity Manual. John Wiley & Sons, Inc., New York, 1932.

This text on electricity for industrial-arts courses is a good work of reference and gives many experiments.

COLLINS, A. FREDERICK. Experimental Mechanics. D. Appleton-Century Company, Inc., New York, 1931.

Various models, levers, linkages, wheels, gears, shafts, movements, and mechanisms are explained, many of which one might easily construct.

COLLINS, A. FREDERICK. Experimental Optics. D. Appleton-Century Company, Inc., New York, 1933.

An unusually good collection of experiments, most of which are not difficult to perform.

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FLINT, W. P., and METCALF, C. L. Insects: Man's Chief Competitors. The Williams & Wilkins Company, Baltimore, 1932.

A superior book on insects, that will appeal to everybody.

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GREENWOOD, ERNEST. Who Pays? Doubleday, Doran and Company, Inc., Garden City, New York, 1934.

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GRIMES, W. E., and HOLTON, E. L. Modern Agriculture. Ginn and Company, Boston, 1931.

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Short Table of Metric Measurements

LENGTH

10 centimeters = 1 decimeter
10 decimeters = 1 METER (about 40 inches)
1000 meters = 1 kilometer (about $\frac{5}{8}$ of a mile)

MASS

10 centigrams = 1 decigram
10 decigrams = 1 GRAM (about 15 grains)
1000 grams = 1 kilogram (about 2 pounds)

CAPACITY

1000 cubic centimeters = 1 LITER (about 1 quart)

SOME EQUIVALENTS

1 inch = 2.540 centimeters
1 mile = 1.61 kilometers
1 pound = 0.4536 kilogram
1 quart = 0.946 liter

Science Words

KEY TO THE SOUNDS

ă *as in* at	ē *as in* be	ō *as in* go	ŭ *as in* us
ā *as in* ate	ẽ *as in* her	ô *as in* horse	ū *as in* use
ȧ *as in* ask	e̥ *as in* vowel	o̥ *as in* connect	u̥ *as in* circus
ä *as in* arm	ĭ *as in* bit	oi *as in* oil	tū *as in* nature
a̤ *as in* sofa	ī *as in* bite	o͞o *as in* food	ŋ *as in* ink
ĕ *as in* bet	ŏ *as in* got	ou *as in* out	

***A* battery.** The battery for heating the filament in a radio tube (p. 522)[1]

abdomen (ăb dō′mĕn). The lower part of the human body. It contains the stomach and intestines (p. 543)

acceleration (ăk sĕl ẽr ā′shu̥n). Rate of change in velocity, or speed (p. 309)

acid. A compound of hydrogen with a nonmetallic element. Acids are sour to the taste and turn litmus paper red (p. 76)

aërial (ā ē′rĭ a̤l). One or several wires connected in such a manner as to receive or send electromagnetic waves (p. 504)

aileron (ā′lẽr ŏn). A mechanism in the wing of an airplane (p. 414)

Airedale. A breed of dog (p. 58)

Aberdeen Angus. A breed of beef cattle (p. 66)

accelerate. To change in velocity (p. 309)

alkaline (ăl′ka̤ lĭn). Like a base. Able to turn litmus paper blue (p. 76)

alloy (a̤ loi′). An intimate mixture of two or more metals (p. 201)

alpaca. Long silky wool from the alpaca, a domesticated beast of burden in the Andes (p. 136)

alternating (ôl′tẽr nāt ĭng) **current (A. C.).** A current of electricity in which the direction of the flow alternates (p. 474)

aluminum (a̤ lū′mĭ nu̥m). Al, a silver-white, light metal (p. 223)

amber. A fossil resin which is brittle, hard, and yellow to brown in color (p. 423)

ammeter (ăm′mē tẽr). An instrument used to measure electric current (p. 489)

ammonia. NH_3, a colorless gas with a characteristic odor, used as a refrigerating agent (p. 621)

ammonium chloride (a̤ mō′nĭ u̥m klō′rīd). A compound used for filling dry cells (p. 258)

ammonium sulfate (sŭl′fāt). An ammonium compound used in the manufacture of fertilizers (p. 165)

ampere (ăm′pēr). A measure of the quantity of electricity flowing past a point in one second (p. 488)

amplitude (ăm′plĭ tūd). The distance through which a vibrating particle moves during wave motion (p. 510)

[1] References are to pages in the text where the words first occur.

anæmia (a̤ nē′mĭ a̤). A disease in which there is a shortage of red blood corpuscles (p. 587)

analysis. The separation of a substance into its parts for study (p. 703)

anatomy. The study of the structure of plants and animals (p. 141)

anneal (a̤ nēl′). To temper glass or metals by heating, then cooling. This makes them less brittle (p. 282)

anther. In the flower of a plant, a case, or hollow ball, which contains pollen (p. 37)

anthrax. A disease of cattle and sheep (p. 641)

anthropology (ăn thrō pŏl′ō jĭ). Science of the origin, races, customs, and beliefs of man (p. 141)

antimony (ăn′tĭ mō nĭ). Sb, a bluish-white, brittle metal (p. 263).

antitoxin (ăn tĭ tŏk′sĭn). A substance which is produced in a living organism and which will overcome the effects of a toxin (p. 592)

aorta (ā ôr′ta̤). The principal artery through which blood leaves the heart (p. 551)

aphid (ā′fĭd). A plant louse (p. 106)

arbutus. A plant belonging to the heath family (p. 80)

arc lamp. An electric lamp in which the current makes a spark, or arc, between two carbon rods (p. 704)

armature. Part of a generator or motor (p. 457)

arsenic. A grayish-black element (p. 263)

artifact. Anything made by primitive man (p. 200)

astigmatism (a̤ stĭg′ma̤ tĭz'm). A defect in the shape of the eye, causing indistinct vision (p. 564)

atom. A small particle, or bit, of substance composed of an equal number of protons and electrons. Molecules are formed of atoms (p. 250)

auditory (ô′dĭ tō rĭ) **nerve.** The nerve which goes to the brain from the ear (p. 566)

auricle (ô′rĭ k'l). One of the two upper chambers of the heart (p. 550)

autogyro (ô′tō jī′rō). A form of airplane (p. 419)

autonomic (ô tō nŏm′ĭk) **nervous system.** A system of nerve tissues which controls such inner organs as the stomach and intestines (p. 559)

Ayrshire. A breed of dairy cattle (p. 65)

***B* battery.** The source of current for the *B* circuit in a radio (p. 522)

bacterium (băk tē′rĭ ṳm) (*pl.* **bacteria** (băk tē′rĭ a̤)). An extremely small, one-celled plant (p. 170)

band. To place a protective band of a substance around the trunk of a tree so that insects cannot crawl up the tree (p. 129)

bank. To tip an airplane as it rounds a curve (p. 299)

barograph (băr′ō grăf). An instrument for recording the changes in the pressure of the atmosphere (p. 317)

base. A compound which unites with an acid to form water and a salt (p. 635)

bauxite (bō′zīt). $Al_2O\ (OH)_4$, a mineral, like clay, from which aluminum may be obtained (p. 269)

belladonna. An herb used in medicine (p. 7)

binding posts. The devices by means of which wires are attached to electrical equipment (p. 249)
biology. The study of living organisms, either plant or animal (p. 44)
bismuth. Bi, a silver-white, brittle metal used to make alloys of low melting points (p. 263)
black-eyed Susan. Yellow daisy (p. 105)
blackheart. Lady's-thumb. A member of a species of plants which has black seeds (p. 108)
blast furnace. A furnace which is used for melting iron ore and in which a blast of hot dry air can be used (p. 212)
bleeder. One who suffers from hæmophilia (p. 585)
blight. A disease of plants, causing withering or decay (p. 165)
blister. A fungus plant (p. 165)
block and tackle. An arrangement of pulleys and ropes (p. 325)
blood pressure. The force with which blood leaves the heart (p. 551)
bloodletting. The practice of withdrawing blood from the body, formerly thought to be of use in the treatment of sickness (p. 579)
bolometer (bō lŏm'ē tẽr). An instrument used to measure small quantities of radiant heat (p. 708)
bore of cylinder. The diameter (p. 388)
breeding grounds. An area in which animals raise their young (p. 144)
British thermal unit (B. T. U.). The amount of heat required to change the temperature of 1 pound of water 1° Fahrenheit (p. 359)
bronze. An alloy of copper and tin (p. 201)
brushes, armature. Small carbon blocks which touch the armature and through which electric current is carried away from the generator (p. 464)
bubonic plague (bū bŏn'ĭk plāg). An epidemic disease which is marked by fevers, chills, and the swelling of certain glands (p. 651)
Bunsen burner. A gas burner in which the air supply can be regulated (p. 281)

cadmium. Cd, a white metal often used to form alloys of low melting points (p. 263)
calcium. Ca, an abundant white metal whose compounds are of great importance (p. 247)
calcium (kăl'sĭ ŭm) **carbonate.** $CaCO_3$; limestone and marble are calcium carbonate (p. 81)
calcium hydroxide (hī drŏk'sīd). $Ca(OH)_2$, a compound produced by the action of water on calcium oxide, called the slaking of lime (p. 286)
calcium oxide (ŏk'sīd). CaO, a compound of calcium and oxygen known as quicklime (p. 286)
cane-borer. An insect which lives in the stem of the sugar-cane plant (p. 16)
capillary. A hairlike tube which connects an artery with a vein (p. 544)
caraway. A plant whose seeds are used as a stimulant (p. 7)
carbohydrate. A chemical compound of oxygen, carbon, and hydrogen. Sugars, starch, and the fibrous parts of vegetables are carbohydrates (p. 182)

carbolic (kär bŏl′ĭk) **acid.** C_6H_5OH, a disinfectant (p. 163)
carbon. An element found as a black solid in coal and coke. It is an essential element for all plant and animal life (p. 235)
carbon dioxide. CO_2, a colorless gas which will neither burn nor support burning. It has many industrial uses. Green leaves use it to make starch. It is given off by the lungs in breathing (p. 75)
carbon monoxide (mŏn ŏk′sīd). CO, a colorless, poisonous gas formed when there is not enough oxygen present for complete burning (p. 235)
carbon tetrachloride (tĕt ra̤ klō′rīd). CCl_4, a colorless liquid used as a fire-extinguisher and as a cleansing agent (p. 127)
carbonic (kär bŏn′ĭk) **acid.** H_2CO_3, an acid formed by the chemical action of water and carbon dioxide (p. 78)
carburetor (kär′bū rĕt ẽr). An instrument in which gasoline vapor and air may be mixed to form an explosive (p. 385)
caribou. A kind of reindeer (p. 56)
caterpillar. The young, or larvæ, of butterflies and moths are called caterpillars (p. 106)
cellulose. A form of carbohydrate. The walls of plant cells are almost entirely cellulose (p. 132)
Centaur. A creature of the Greek myths, half man and half horse (p. 579)
centigrade thermometer. A scale of a thermometer on which the freezing point of water is marked as 0° and the boiling point as 100° (p. 350)
centrifugal (sĕn trĭf′ū ga̤l) **force.** A whirling body has a tendency to move outward from its center. This force acting away from the center is called centrifugal force (p. 298)
cerebrospinal (sĕr ē brō spī′na̤l) **nervous system.** The system of nerve tissues including the brain, the spinal cord, and related nerves (p. 559)
cerebrum (sĕr′ē brṳm). The upper portion of the brain (p. 573)
chaulmoogra (chôl mo͞o′gra̤) **oil.** A yellow oil taken from the seeds of certain plants in India and used for treating the disease known as leprosy (p. 7)
chemistry. The science which studies the composition of substances and the changes in their composition (p. 209)
chinch bug. An insect very destructive to grain (p. 186)
chinchilla. A rodent, much like the squirrel, found in the Andes (p. 70)
chlorine (klō′rēn). A greenish-yellow poisonous gas (p. 251)
chlorophyll (klō′rō fĭl). The green coloring matter of plants (p. 165)
chromium (krō′mĭ ṳm). Cr, a silver-white, hard metal. It is used to harden steel (p. 217)
chromosomes (krō′mō sōmz). Small bodies in the germ cells; they have the power to determine the heredity of the next generation (p. 35)
chrysalid (krĭs′a̤ lĭd). A pupa (the third stage) of an insect, especially the pupa of a butterfly (p. 106)
cinchona (sĭn kō′na̤). A tree, native of the Indies; from its bark quinine is obtained (p. 7)
climax organism. A living thing, as a plant or an animal, which lives and flourishes in a region for a long period of time (p. 115)

clutch. A mechanism by means of which the power from the engine of an automobile may be easily connected with the rear wheels or disconnected from them (p. 390)

clutch shaft. A short piece of steel to carry power from the clutch to the transmission gears (p. 390)

cobalt. A steel-gray metal used in alloys (p. 440)

cobra (kō'bra̤). A very poisonous snake of the warm parts of Asia (p. 136)

cockroach. An insect often found near water pipes in kitchens (p. 186)

coleus (kō'lē u̥s). An ornamental plant (p. 158)

Colorado potato beetle. A beetle which eats potato vines (p. 186)

color-blind. Unable to distinguish colors, yet able to see forms (p. 565)

combine (kŏm'bīn). A harvesting machine which cuts and threshes grain in one operation (p. 220)

commutator. A device for changing alternating current to direct current (p. 463)

compost (kŏm'pōst). Decaying material to be used as fertilizer (p. 84)

compound. A single substance composed of two or more elements (p. 76)

compound bar. A bar of two or more strips of different metals riveted together (p. 616)

compressed air. Air which is pressed together by more than the normal pressure of the atmosphere. Automobile tires contain compressed air (p. 281)

concave (kŏn'kāv). A mirror or lens which is thicker at the edges than in the center is said to be concave (p. 688)

concentration. The amount or portion of one substance found dissolved in or mixed with another substance (p. 224)

concept. An idea, or thought (p. 321)

condensation. A crowding together, becoming more close (p. 508)

condenser. An electrical device on which electrons may be lodged for a short time (p. 521)

conduction. The transfer of heat or electricity through a substance, as through a copper bar (p. 610)

conductor. Anything which carries or conducts, as a conductor of electricity or a conductor of heat (p. 253)

contact screw. A screw which may be adjusted in such a manner as to form a contact and so complete an electrical circuit (p. 457)

contraction. Drawing together; becoming shorter or smaller (p. 547)

convection. The transfer of heat in air or water by means of currents (p. 610)

converter. A large pear-shaped iron container which holds the liquid iron while oxidation of the impurities takes place (p. 238)

convex lens. A lens which is thicker in the center than at the edges (p. 682)

copper. Cu, a red metal, used for conducting electricity, and as a part of many alloys (p. 129)

copperhead. A copper-colored poisonous snake (p. 106)

copper sulfate. $CuSO_4$ (blue vitriol), a poisonous copper compound used as a spray for plant diseases (p. 265)

coral snake. A poisonous snake found in the southern part of the United States (p. 106)

cornea (kôr′nē ạ). The transparent part of the coat of the eyeball. It covers the iris and pupil (p. 562)

corpuscle (kôr′pŭs′l). A small cell floating in the blood or lymph of the body (p. 586)

cortex. The outer layer of the gray matter of the brain (p. 573)

cosmic (kŏz′mĭk) **rays.** Rays coming to the earth from outer space (p. 674)

cotton-boll weevil. A small beetle which does much damage to the cotton plant (p. 186)

crank shaft. The piece of steel which is made to turn by the motor of the automobile (p. 390)

creosote. An oily, tarlike liquid (p. 191)

Cro-Magnon (krō-mạ nyôn′). A race of early man, named after a cave in France (p. 204)

crossbreeding. The crossing, or mating, of two varieties in order to produce a different type of individual (p. 6)

cross-fertilize. To fertilize an egg cell from one plant with a sperm cell of another plant (p. 38)

cross-pollination. The transfer of pollen from one plant to another (p. 36)

cuprite (kū′prīt). Cu_2O, a copper ore (p. 209)

curd. The substance formed when milk curdles (p. 636)

cutting. A small piece of a plant, as a short stem, which when placed in soil and carefully grown will form a new plant (p. 31)

cylinder. A hollow chamber in an external-combustion or internal-combustion engine; in it an expanding gas can push against a piston which in turn can move other parts (p. 371)

damsel fly. An insect whose nymph stage is spent in water, while the adult stage is spent in the air (p. 184)

decompose (dē kọm pōz′). To split up into elements or simpler compounds, as water may be decomposed into oxygen and hydrogen (p. 85)

demagnetize (dē măg′nĕt īz). To remove magnetic properties (p. 442)

density. The amount of material or matter per unit of volume (p. 226)

deposit. An amount of material, as an ore or clay found somewhat close together on or near the surface of the earth (p. 224)

diaphragm (dī′ạ frăm). A disk or membrane free to move forward and backward, as in a telephone transmitter (p. 512)

Diesel (dē′zẹl) **engine.** A form of internal-combustion engine in which the explosion takes place at high temperatures and pressures without the presence of a spark (p. 395)

differential gears. A set of gears in the rear axle to allow one rear wheel to turn independently of the other (p. 391)

digitalis (dĭj ĭ tā′lĭs). The seeds or leaves of the foxglove, used in medicine (p. 7)

dip. The tip of a compass from a horizontal position (p. 450)

direct current (D.C.). A current of electricity in which the direction of the flow remains the same (p. 476)

distributor. A mechanism to supply electricity to the cylinders of a gasoline engine at the proper time (p. 393)

diversify. To cause variety and difference (p. 31)

dock. A kind of weed (p. 159)

dogbane. A plant whose milky juice is poisonous (p. 160)

dominant characteristics. Those characteristics which appear in the first generation of hybrids (p. 47)

Doppler (dŏp′lẽr) **effect.** The rise or fall in the pitch of sound produced by the approach or departure of the source (p. 705)

draft horse. A horse able to pull heavy loads (p. 64)

drive shaft. The rotating piece of steel which connects the clutch with the rear axle in an automobile (p. 390)

drone. A male bee (p. 180)

dry cell. A device for changing chemical energy to electrical energy (p. 452)

duralumin (dū răl′ū mĭn). A strong, hard alloy of copper, magnesium, manganese, and aluminum (p. 271)

durum (dū′rum) **wheat.** A variety of spring wheat which has hard kernels (p. 40)

Dutch elm disease. A disease of the elm tree caused by a fungus (p. 165)

dynamo. A machine for producing electrical energy from mechanical energy (p. 454)

eccentric (ĕk sĕn′trĭk). A device in the steam engine to control the movements of the slide valve (p. 372)

ecliptic (ē klĭp′tĭk). The circle made by the plane of the earth's orbit as it cuts the heavenly sphere (p. 694)

economic (ē kō nŏm′ĭk). That which has to do with the production and use of wealth is economic (p. 27)

egg cell. A female germ cell (p. 35)

electric charge. When an object has more or less than the normal number of electrons, it is said to have an electric charge (p. 429)

electric motor. An engine which can change electrical energy to mechanical (kinetic) energy (p. 462)

electrolysis (ē lĕk trŏl′ĭ sĭs). The process of breaking down, or decomposing, a substance by the use of an electric current (p. 265)

electromagnet. An instrument which has magnetic properties caused by the passage of a current of electricity through a wire wound around a core of soft iron or soft steel (p. 451)

electromagnetic waves. Waves of radiant energy produced by the magnetism of electricity (p. 519)

electron (ē lĕk′trŏn). A unit charge of negative electricity (p. 250)

electroplating (ē lĕk′trō plāt ĭng). The process of plating by electrolysis, as plating with silver or copper (p. 265)

electroscope (ē lĕk′trō skōp). An instrument for studying electrically charged bodies (p. 431)

element. A substance which cannot be decomposed into more simple substances (p. 75)

energy. Ability to do work (p. iii)

eohippus (ē ō hĭp'u̯s). A prehistoric animal somewhat like the modern horse (p. 63)

equation, chemical. A short statement of a chemical change (p. 234)

ermine (ẽr'mĭn). A small animal somewhat like a weasel (p. 135)

erosion (ē rō'zhu̯n). The wearing away of land by forces of nature (p. 94)

esophagus (ē sŏf'a̱ gu̯s). The tube leading from the mouth to the stomach (p. 542)

eucalyptus (ū ka̱ lĭp'tu̯s). A tree from whose leaves a medicine is made (p. 7)

European elm-bark beetle. A beetle introduced from Europe, which injures the bark of elm trees (p. 170)

exoskeleton (ĕk sō skĕl'ē tu̯n). The hard outside covering or shell which protects the body of certain animals (p. 175)

external-combustion engine. A type of engine, such as the steam engine, in which combustion of the fuel takes place outside the cylinder (p. 376)

extract. To separate or purify, as a metal may be extracted from its ore (p. 224)

fallow (făl'ō). Left bare, unplanted, as land is left fallow for a year (p. 88)

feldspar. A mineral containing aluminum. When it decomposes, clays are formed (p. 225)

fennel. The fruit of the fennel is used in medicine (p. 7)

fibrovascular (fī brō văs'kū lẽr) **bundles.** Strands of cells in certain plants; they strengthen the stems (p. 15)

filament. A piece of wire, usually tungsten, placed in an electrical circuit, as a vacuum tube, so that it may glow or give off electrons (p. 522)

flycatcher. A bird that catches insects while flying (p. 107)

flywheel. A heavy wheel attached to certain engines; its motion helps the engine to run smoothly (p. 371)

focal (fō'ka̱l) **length.** The distance from a lens to the point at which rays passed through it come together (p. 682)

focus. To cause rays, such as rays of light, to meet after passing through a lens (p. 347)

foot-pound. A measure or unit of work (p. 548)

forced draft. A draft of air pumped or forced into a fire box to cause rapid burning of the fuel (p. 210)

formula. A group of symbols which represent a compound, as H_2O is the formula for water (p. 209)

forsythia (fŏr sĭth'ĭ a̱). An early-blooming shrub (p. 50)

fossil (fŏs'ĭl). Any trace or remains of life in past ages is said to be a fossil (p. 8)

Fraunhofer (froun'hō fẽr) **lines.** Dark lines in the spectrum of the sun (p. 704)

fulcrum (fŭl'kru̯m). The point about which a lever turns (p. 326)

fungus (fŭŋ'gus) (*pl.* **fungi** (fŭn'jī)). Fungus plants have no green coloring matter and cannot make their own food as can other kinds of plants (p. 159)

fuselage (fū'ze lĭj). The inclosed portion or body of an airplane (p. 418)

galaxy (găl'ak sĭ). An enormous group of stars (p. 715)

galvanized iron. Sheet iron which is covered with a thin layer of zinc (p. 259)

galvanometer (găl va nŏm'ē tẽr). An instrument to show the presence or direction of an electric current (p. 252)

ganglion (găŋ'glĭ on) (*pl.* **ganglia**). A nerve center in the nervous system (p. 574)

gaseous. Like a gas (p. 357)

gauge (gāj). An instrument which indicates pressures (p. 376)

gear box. The box which incloses the transmission gears (p. 390)

gear wheel. A wheel with gears (p. 325)

gene (jēn). A small body within the chromosomes which determines a characteristic, or quality, of the organism of which it is a part (p. 38)

generate (jĕn'ẽr āt). To develop or produce (p. 288)

generator, electric. A machine which changes mechanical (kinetic) energy to electrical energy (p. 367)

gentian (jĕn'shan). A plant whose roots are used in medicine in the preparation of a bitter tonic (p. 7)

gland. An organ of the body which produces a secretion, as the liver

glucose (gloo͞'kōs). $C_6H_{12}O_6$, a form of sugar found in the juices of many plants; often called grape sugar or dextrose (p. 13)

glycogen (glī'kō jĕn). $C_6H_{10}O_5$, a carbohydrate found in large amounts in the liver (p. 545)

grackle (grăk''l). A kind of blackbird (p. 107)

grain. The common pound contains 7000 grains (p. 610)

gram-calorie. The amount of heat required to raise the temperature of 1 gram of water 1° C. (p. 359)

granite. A fire-formed rock which has cooled under great pressure (p. 227)

graphite (grăf'īt). A form of carbon whose crystals are like small flakes (p. 265)

gravitation (grăv ĭ tā'shun). The attraction between all bodies of matter, as between the sun and the earth or between the earth and objects upon it (p. 295)

great circle of a sphere. A circle whose plane passes through the center of the sphere (p. 661)

green manure. Plants which are grown for the purpose of being plowed under in order to fertilize soil (p. 84)

grid. A piece of woven metal to and through which electrons flow from the filament in the vacuum tube (p. 522)

grub. The thick, wormlike larva of an insect (p. 180)

guano (gwä'nō). Waste product of birds; it is used as manure (p. 86)

Guernsey (gûrn'zĭ). A breed of dairy cattle (p. 65)

gypsy moth. A moth whose larva is very destructive to trees (p. 106)

habitat (hăb′ĭ tăt). The environment in which a plant or an animal lives (p. 80)

hæmophilia (hē mō fĭl′ĭ a̤). The tendency to continued bleeding, even from slight wounds (p. 585)

hair follicle. A gland from which hair grows (p. 70)

head. The vertical distance through which water flows before turning the turbine which drives the electric generator (p. 485)

helium (hē′lĭ u̯m). He, a gaseous element. Recently it has been used to fill dirigibles (p. 716)

hematite (hĕm′a̤ tīt). Fe_2O_3, the most common iron ore used for the manufacture of iron (p. 210)

heredity (hē rĕd′ĭ tĭ). The tendency of offspring to develop characteristics like those of their parents (p. 34)

Hereford (hĕr′ē fẽrd). A breed of cattle raised for beef (p. 62)

Holstein (hōl′stīn). A breed of cattle raised for milk production (p. 62)

hookworm. A parasite which lives in the small intestine in man (p. 588)

hormones (hôr′mōnz). The substances produced by the glands of internal secretion (p. 586)

horsepower. A unit of work equal to 33,000 foot-pounds per minute (p. 287)

humidifier (hū mĭd′ĭ fī ẽr). A device used to evaporate water into the surrounding air in order to make the air more humid (p. 620)

humidity. The amount of water vapor in the air (p. 607)

humus. Fertilizer composed of decaying plant matter (p. 77)

husky. An Eskimo dog (p. 57)

hybrid (hī′brĭd). The offspring of parents of different species, or varieties (p. 31)

hybridizer (hī′brĭd īz ẽr). One who is skilled in producing hybrid plants or animals (p. 31)

hydrochloric (hī drō klō′rĭk) **acid.** HCl, a solution of hydrogen chloride in water (p. 248)

hydroelectric (hī drō ē lĕk′trĭk). Having to do with the production of electric power by the use of water (p. 470)

hydrogen sulfide. H_2S, a colorless gas having the odor of rotten eggs (p. 644)

igneous (ĭg′nē u̯s). Having to do with rocks formed from hot liquid material, as lava and granite (p. 225)

ignition (ĭg nĭsh′u̯n) **circuit.** The wires and spark plugs through which the electricity flows to produce a spark in the cylinders (p. 387)

immune (ĭ mūn′). Able to resist disease (p. 167)

incinerator (ĭn sĭn′ẽr ā tẽr). A building or furnace in which garbage may be burned at high temperatures (p. 647)

incubation (ĭn kū bā′shu̯n). The process of development in an egg before the young is hatched (p. 69)

induced current. A current made to flow in one coil of wire (the secondary) because of the flow of current in a coil (the primary) near by (p. 495)

induction coil. An electrical device so constructed that pulsating currents may be produced in a second circuit by making and breaking a current in a primary circuit

infra-red rays. Rays whose wave length is longer than that of red rays (p. 679)

instinct. An unlearned tendency to perform certain actions in a certain manner under certain conditions (p. 176)

insulate. To separate by nonconductors, thus preventing the passage of heat or electricity (p. 431)

insulator (ĭn′sū lā tẽr). A substance which does not conduct electricity or heat to any extent (p. 427)

insulin (ĭn′sū lĭn). A secretion of the pancreas; it regulates the use of sugar by the body (p. 585)

intake valve. A valve which opens toward the inside only (p. 385)

interferometer (ĭn tẽr fẽr ŏm′ē tẽr). An instrument which can measure small distances by the interference of two beams of light (p. 708)

internal-combustion engine. A type of engine in which combustion occurs within the cylinder (p. 383)

internode. The space between the nodes on the stem of a plant (p. 14)

interrupter. A piece of soft iron used as a magnet to make and break a circuit in certain electrical instruments (p. 520)

invar (ĭn vär′). An alloy of nickel and iron (p. 273)

ion (ī′ọn). An atom which has gained or lost electrons (p. 429)

iris (ī′rĭs). The colored portion of the eye (p. 562)

iron, cast. A brittle iron which can be poured into molds and made into castings (p. 237)

iron, wrought (rôt). An iron which can be shaped or hammered, as at a forge (p. 237)

Japanese beetle. A species of beetle introduced from Japan, which is quite destructive to plant life (p. 189)

Jersey. A breed of cattle whose milk is rich in cream (p. 65)

juniper (jo͞o′nĭ pẽr). A tree whose fruits are used in medicine and as a tea (p. 7)

kaolin (kā′ō lĭn). A porcelain clay (p. 269)

kidneys. Two organs located in the lower part of the body cavity which secrete waste liquids (p. 554)

kilocycle (kĭl′ō sī k'l) **(Kc.).** One thousand cycles (p. 526)

kilogram-calorie. An amount of heat required to change the temperature of 1 kilogram of water 1° C. (p. 548)

kilowatt (kĭl′ō wŏt) **(kw.).** A measure of electric power (p. 491)

kilowatt-hour. A kilowatt of electrical power used for one hour (p. 491)

kindling temperature. The temperature at which a substance will begin to burn (p. 126)

kinetic (kĭ nĕt′ĭk) **energy.** The energy of any moving object (p. 340)

larva (*pl.* **larvæ** (lär′vē)). The eggs of many insects hatch into forms known as larvæ (p. 114)

larynx (lăr'ĭŋks). The part of the windpipe which holds the vocal cords (p. 505)
lead peroxide. PbO_2, a compound of lead and oxygen (p. 260)
leaf hopper. A kind of grasshopper (p. 16)
legume (lĕg'ūm). A plant on whose roots grow nitrogen-fixing bacteria (p. 89)
levulose (lĕv'ū lōs). $C_6H_{12}O_6$, fruit sugar (p. 181)
life cycle. The complete life of an organism from birth to death (p. 588)
light-year. The distance which light will travel in a year at its speed of about 186,000 miles per second (p. 707)
limestone. A sedimentary rock composed chiefly of calcium carbonate (p. 85)
lines of force. A region around a magnet or electric wire in which it may be shown that there is a magnetic field by the arrangement of iron filings in "lines of force" (p. 442)
lithium (lĭth'ĭ um). Li, a silver-gray metallic element (p. 704)
litmus paper. A paper whose coloring matter is used to indicate the presence of an acid or a base (p. 635)
litter. Young animals born at one time (p. 645)
loam. Soil which contains abundant humus (p. 75)
loco weed. A poisonous weed found in the western part of the United States (p. 160)
locust. A kind of grasshopper (p. 184)
lunar (lū'nẽr). Having to do with the moon (p. 670)
lupine (lū'pĭn). A plant belonging to the bean family; a legume (p. 88)

magnalium (măg nā'lĭ um). An alloy of aluminum and magnesium (p. 271)
magnetism. The properties or qualities of a magnet (p. 439)
magnetite (măg'nĕt īt). Iron ore which has the properties of a magnet (p. 225)
magnitude. In astronomy, the degree of brightness of a star
maize (māz). A plant whose seeds are borne on a large stalk, or ear. Also called Indian corn or corn (p. 9)
malaria. A disease caused by the bite of the *Anopheles* mosquito (p. 588)
mammals. Animals whose young are raised on milk (p. 137)
manganese (măŋ ga nēs'). Mn, a grayish-pink, brittle metal, used in alloys with iron, copper, and silicon (p. 240)
mantis (măn'tĭs) (*pl.* **mantes** (măn'tēz)). A kind of insect related to the grasshopper (p. 174)
marmot (mär'mot). A kind of small animal with coarse hair (p. 70)
mastoid process. The projecting bone behind the ear (p. 566)
measuring worm. The caterpillar, or larva, of a kind of moth (p. 186)
mechanical advantage. In a machine the ratio of the resistance to the effort required to overcome that resistance (p. 326)
mechanism (mĕk'an ĭz'm). A system of parts which act together as a machine (p. 35)
melting point. The temperature at which a solid changes to a liquid (p. 227)

Mendelian (mĕn dē'lĭ a̤n) **laws.** Laws of heredity discovered by Mendel (p. 51)

mercury. Hg, quicksilver; a silver-white metallic liquid. Used in thermometers and barometers, and in many industrial processes (p. 552)

metamorphosis (mĕt a môr'fō sĭs). A change of form, as the change from the pupa stage to the adult stage of many insects (p. 176)

meteorite (mē'tē o̤r īt). A body which has fallen to the earth from outer space (p. 369)

meter. An instrument for measuring and recording the amount and flow of a substance, as a gas meter (p. 499)

Mexican bean beetle. A beetle which injures bean plants (p. 186)

mica (mī'ka̤). A form of silicon which can be split into very thin sheets. It is used as an insulator for electrical equipment. Often called isinglass (p. 226)

microörganism (mī krō ôr'ga̤n ĭz'm). A living plant or animal so small that it can be seen only with the aid of a microscope (p. 588)

microphone. A transmitter for a radio set (p. 505)

migratory (mī'gra̤ tō rĭ). Moving from one place to another (p. 148)

milk sugar. The sugar found in milk; lactose (p. 635)

Milky Way. The immense group, or galaxy, of stars of which the sun is a part (p. 713)

modulate (mŏd'ū lāt). To regulate or soften. In radio use, to affect the carrier wave so that sounds may be reproduced from it (p. 529)

mold. A kind of fungus plant (p.166)

molecular theory. The belief that all matter is made up of very small particles called molecules (p. 354)

molecule (mŏl'ē kūl). The smallest part into which a substance may be divided and yet retain the characteristics of the substance (p. 295)

molybdenum (mō lĭb'dē nṳm). Mo, a gray, heavy metal. Crank shafts and connecting rods are made of steel containing molybdenum (p. 272)

mongoose (mŏŋ'gōōs). A small animal, native of India (p. 136)

motor. A machine for producing mechanical energy from another form, as from electrical energy (p. 454)

motor neuron. A neuron which carries an impulse to a muscle or a gland (p. 570)

mucous (mū'kṳs) **membrane.** The tissue which lines such body openings as the nose and the throat (p. 162)

mucus. The liquid in the linings of such body openings as the nose and the throat (p. 592)

mullein (mŭl'ĭn). A weed with coarse woolly leaves and spikes of yellow flowers (p. 159)

mutant (mū'ta̤nt). An offspring whose characteristics are not those which might be expected in the light of the characteristics of its parents and of the generations preceding.

narcotic (när kŏt'ĭk). A drug which in small doses relieves pain and produces sleep but in large doses produces stupor (p. 598)

Neanderthal (nā än′dẽr täl) **man.** An early type of man named after a valley in a Rhine province (p. 203)
nebula (nĕb′ū la̤) (*pl.* **nebulæ** (nĕb′ū lē)). An object in the heavens which appears to be hazy when viewed through a telescope (p. 717)
nebular theory. A theory which attempted to explain the origin of the solar system. It is no longer accepted (p. 713)
nectar (nĕk′ta̤r). A sweet liquid found in many flowers (p. 178)
negative ion. A particle formed from an atom in a chemical or electrical change in which an electron has been gained (p. 251)
Neolithic (nē ō lĭth′ĭk) **Age.** A period of time, following the Paleolithic Age, in which stone tools were improved (p. 206)
nerve cell. A small bit of living matter with a nucleus, or center, and usually two branches along which a nerve current may flow (p. 560)
nerve fiber. one of the slender threads or branches of the nerve cell (p. 560)
neuron (nū′rŏn). A nerve cell with its branches (p. 568)
neutral. An electrical condition in which there is a balance of electrons and protons (p. 429)
nichrome (nī′krōm). An alloy of nickel, iron, and chromium (p. 490)
nickel. A silver-white metal, used in the making of stainless steel, and for electrical apparatus and surgical instruments (p. 440)
nitric acid. HNO_3, a powerful and important acid (p. 85)
nitrite (nī′trīt). A salt formed from nitrous acid (p. 171)
nitrogen (nī′trō je̤n). A colorless, odorless, tasteless gas (p. 84)
nitrogen-fixing bacteria. Bacteria whose life activity while attached to the roots of certain plants (legumes) causes nitrogen to become lodged in soil (p. 90)
node. The joint of a stem, where a leaf may be borne (p. 14)
nymph (nĭmf). The second stage in the life cycle of those insects which have only three stages: egg, nymph, adult (p. 184)

objective lens. The lens toward the object being studied, in a telescope or a microscope (p. 687)
offspring. That which grows from or is born from something (p. 32)
ohm (ōm). A measure of the resistance of a conductor to the flow of electricity through it (p. 488)
oil-cracking. A process in which crude oils are refined under very high temperatures and pressures (p. 731)
olfactory (ŏl făk′tō rĭ). Having to do with the sense of smell (p. 566)
open-hearth process. A process of manufacturing steel (p. 238)
optic (ŏp′tĭk) **nerve.** The nerve which goes to the brain from the eye (p. 562)
optician (ŏp tĭsh′a̤n). One who makes or deals in optical glass and instruments (p. 693)
optics. Having to do with the eye (p. 706)
ore. A mineral from which a metal may be profitably extracted (p. 197)
organic (ŏr găn′ĭk). Having to do with plant or animal life (p. 643)
organism (ôr′gan ĭz′m). A living individual, either animal or plant (p. 113)

ovary (ō′va̤ rĭ). The hollow portion of the pistil, in which the seeds develop (p. 36)
ovule (ō′vūl). A developing seed in the ovary (p. 36)
oxidation (ŏk sĭ dā′shu̦n). The union of oxygen with some other substance (p. 78)
oxide (ŏk′sīd). A compound composed of oxygen and one other element (p. 225)
oxidize. To combine with oxygen (p. 340)

Paleolithic (pā lē ō lĭth′ĭk) **Age.** The period of time which includes the earliest development of human culture (p. 206)
Paleozoic (pā lē ō zō′ĭk) **era.** A large division of earth history (p. 229)
pancreas (păn̦′krē ăs). A gland below the stomach; it secretes a fluid that aids digestion (p. 585)
parasite. An organism that lives in or on another at the expense of the latter (p. 106)
parathyroid (păr a̤ thī′roid) **gland.** A small gland near the thyroid gland (p. 585)
patent medicine. A medicine whose composition is patented (p. 602)
pedigree. A list of ancestors (p. 73)
Pekingese. A small, long-haired dog (p. 57)
pelagic (pē lăj′ĭk). That which has to do with the deep sea (p. 144)
penstock. A large pipe through which water flows rapidly in order to turn a turbine for an electric generator (p. 485)
pharmacology (fär ma̤ kŏl′ō jĭ). The science of drugs (p. 599)
phases (fāz′e̤z) **of the moon.** The four stages, or periods, in appearance of the moon as seen from the earth (p. 670)
phlox (flŏks). A plant cultivated for its showy flowers (p. 192)
phosphorus (fŏs′fo̤r u̦s). P, a soft yellow or red solid which burns readily upon exposure to air (p. 84)
photoelectric cell. A vacuum tube so constructed that various forms of radiation, as light, falling upon the potassium within, cause electrons to flow, thus completing an electric circuit (p. 680)
physical properties. Qualities, or characteristics, which are present in a substance and give it its particular nature (p. 274)
pigweed. A common weed (p. 108)
piston. The moving part inside a cylinder (p. 371)
pitch. The distance between two threads. Of a propeller, the distance it would move forward in one turn if it were screwed into a solid substance (p. 409)
pith ball. A small, light ball made from the inside of the stem of a plant (p. 425)
pituitary (pĭ tū′ĭ tĕr ĭ). A small gland in the brain (p. 585)
planetesimals (plăn ĕt ĕs′ĭ ma̤lz). The small bodies which were torn from the sun (in the planetesimal theory) and which moved in space somewhat as planets do at present (p. 711)
plant lice. Small insects which live upon the sap of plants (p. 182)
plantain (plăn′tān). A common weed with large spreading leaves close to the ground (p. 159)

plasma (plăz'mạ). The liquid part of the blood (p. 584)
plate. A piece of metal, placed in a vacuum tube, to which electrons flow from the filament (p. 521)
platinite. An alloy of nickel and iron (p. 273)
platinum. Pt, a silver-gray metal used in certain chemical reactions and for some jewelry (p. 223)
pneumatics (nū măt'ĭks). The study of the physical properties, or qualities, of air and other gases (p. 728)
poison sumac (sū'mak). A shrub whose foliage is poisonous (p. 161)
poke weed. A coarse weed whose berries and roots are poisonous. It was used as dye by Indians (p. 160)
polarity (pō lăr'ĭ tĭ). An electrical condition which is described by the terms *north pole* and *south pole* (p. 464)
pollute (pọ lūt'). To make impure (p. 149)
positive ion. A particle formed from an atom in a chemical or electrical change in which an electron has been lost (p. 250)
potash (pŏt'ăsh) (**potassium** (pō tăs'ĭ ụm) **hydroxide**). KOH, a compound of potassium, hydrogen, and oxygen used in the manufacture of soap and glass
potassium (pō tăs'ĭ ŭm). K, a silver-white, soft metal (p. 84)
potential (pō tĕn'shạl) **energy.** Energy which is stored or inactive but which can become active (kinetic) (p. 339)
power. The rate of doing work (p. 323)
precipitate (prē sĭp'ĭ tāt). To condense a vapor into a liquid or to deposit a solid from a solution in which it is dissolved (p. 113)
predator (prĕd'ạ tẽr). An organism that preys upon another organism, or living thing (p. 186)
primary coil. The coil in an electrical circuit attached to the source of the current (p. 497)
projection. A part which sticks out (p. 38)
proton (prō'tŏn). A unit charge of positive electricity (p. 250)
protoplasm (prō'tō plăz'm). The living substance of which plant and animal cells are composed (p. 78)
Protozoa (prō tō zō'ạ). A group of animals whose bodies consist of a single cell (p. 588)
pulmonary (pŭl'mō nā rĭ) **artery.** The artery leading from the right ventricle of the heart into the lungs (p. 550)
pulmonary vein. The vein through which the blood returns from the lungs to the heart (p. 550)
pulse. A legume (p. 88)
pupa (pū'pạ) (*pl.* **pupæ**). The term used to describe an insect in its resting stage inside a cocoon (p. 176)
pupate. Insects in the pupal stage are developing, or pupating; that is, becoming ready to leave the cocoon as adults (p. 185)
pusley (pŭs'lĭ). A common plant sometimes used for salad or for flavoring (p. 108)

quartz (kwôrts). A form of silica, SiO_2, in crystal form (p. 225)
Queen Anne's lace. The wild carrot (p. 105)

quicklime. Calcium oxide (p. 286)
quinine (kwī′nīn). $C_{20}H_{29}O_2N_2$, a drug obtained from the bark of the cinchona tree (p. 599)

radiant (rā′dĭ ạnt) **energy.** Energy which travels in waves, as sunlight (p. 348)
radiation (rā dĭ ā′shụn). The process of transferring energy from a body through space (p. 352)
radioactive elements. Elements which are the source of certain radiations. Such elements break up, becoming other substances (p. 711)
radiometer (rā dĭ ŏm′ē tẽr). An instrument which demonstrates the energy of the sun's rays (p. 345)
radium (rā′dĭ ụm). Ra, a radioactive element discovered in 1898 (p. 711)
ragweed. A weed, the pollen of which is one cause of hay fever (p. 108)
rarefaction (râr ē făk′shụn). A spreading out; becoming farther apart (p. 508)
ratoon (rạ to͞on′). A sugar-cane stalk (p. 16)
rayon. An artificial silk made from cellulose (p. 132)
reacting organ. Any organ which functions, or acts, as a result of stimuli received from a sense organ (p. 561)
reaction (rē ăk′shụn). Response to a stimulus (p. 570)
receptor (rē sĕp′tẽr). A small sense organ which is able to receive and pass on stimuli, such as light or sound (p. 561)
recessive (rē sĕs′ĭv) **characteristics** (kăr ạk tẽr ĭs′tĭks). Those characteristics which do not appear in the first generation of hybrids (p. 47)
redtop. A grass used in pastures and lawns (p. 105)
refine. To purify (p. 267)
reflecting telescope. A form of telescope in which the light is brought to a focus by a mirror (p. 284)
reflex (rē′flĕks) **action.** A simple action brought about because of a connection from a sense organ through the spinal cord to an organ which acts (p. 568)
refracting telescope. A form of telescope in which the light passes through an objective lens so that the image is magnified by the eyepiece lens (p. 689)
refrigerating agent. A substance which is of value in mechanical refrigeration because of the ease with which it may be changed from a liquid to a gas at ordinary temperatures (p. 622)
relative humidity (hū mĭd′ĭ tĭ). The ratio between the amount of water vapor present in the air and the amount required to saturate the air at that temperature (p. 607)
reservoir (rĕz′ẽr vwôr). A storage place for water (p. 288)
retina (rĕt′ĭ nạ). The receptor organ for vision (p. 562)
Rhode Island Red. A variety of chicken (p. 67)
rhododendron (rō dō dĕn′drọn). A large evergreen shrub (p. 80)
rodent. Any gnawing animal (p. 107)
rods and cones. The small receptor organs for vision, located in the retina (p. 562)
rookery. A breeding ground of seals and certain birds (p. 147)

rotation (rō tā′shṳn) **of crops.** The regular change of field crops for the purpose of maintaining the fertility and texture of the soil (p. 88)
rotor (rō′tẽr). The shaft of a generator or of a turbine (p. 481)
rust. A fungus plant (p. 165)
rutabaga (ro͞o tạ bā′gạ). The yellow turnip (p. 91)

sandstone. A stone composed of fine grains of sand which were cemented together under natural conditions (p. 277)
saprophyte (săp′rō fīt). A plant which secures its food from the dead body of another plant or animal (p. 166)
sarsaparilla (sär′sạ pạ rĭl′ạ). A plant whose root is used as a tonic (p. 7)
satellite (săt′ẹ līt). A heavenly body revolving about another as the moon, a satellite, revolves about the earth (p. 709)
scale insects. Insects which attach themselves to plants and have the appearance of scales (p. 182)
scallop (skŏl′ṳp). A shellfish somewhat like a clam (p. 152)
scarab beetle. A kind of beetle considered sacred in ancient Egypt (p. 174)
sea lion. A kind of seal (p. 144)
secondary coil. The coil, in an electrical circuit, in which a current is made to flow by a current passing through a near-by coil called the primary coil (p. 497)
secretion (sē krē′shṳn). A substance produced by some organ of an animal or a plant (p. 585)
selection. A method of securing more desirable plants or animals by carefully choosing certain individuals to be parents (p. 6)
sensation. If a receptor is stimulated, or aroused, by a color or warmth, it may be said to have received the sensation of color or warmth (p. 561)
sensitive. Able to respond easily and readily (p. 561)
sensory neuron. A neuron which carries an impulse from a sense organ (p. 568)
septic tank. A tank in which sewage may be changed into liquid matter and gases by the action of bacteria (p. 649)
setter. A long-haired hunting dog (p. 59)
shad. A fish of the North Atlantic coast, used for food (p. 137)
Shropshire. An English breed of hornless black-faced sheep (p. 66)
shunt. A side circuit for the flow of electricity (p. 489)
sidereal (sī dē′rē ạl) **time.** A system of reckoning time; it is based on a star instead of on the sun (p. 670)
silica (sĭl′ĭ kạ). Silicon dioxide (p. 225)
silicon dioxide (silica). SiO_2, a compound of silicon and oxygen (p. 223)
silt. Material, as sand and dirt, carried by water and deposited when the current becomes slow (p. 77)
skeletal. Having to do with the skeleton (p. 542)
slag. Cinderlike material produced during the smelting of iron (p. 234)
slide valve. A sliding valve which allows steam to enter the cylinder of a steam engine (p. 371)
smut. A fungus plant (p. 165)

sodium. Na, a soft silver-white metal. Combined with chlorine it forms common table salt (p. 246)
sodium carbonate. Na_2CO_3, washing soda (p. 279)
sodium chloride. NaCl, common table salt (p. 245)
sodium hydroxide. NaOH, a compound of sodium, hydrogen, and oxygen much used in industry (p. 246)
sodium nitrate. $NaNO_3$, Chile saltpeter (p. 85)
solar. Having to do with the sun (p. 664)
solar (sō'lẽr) **day.** A day whose length is based upon the relationship of the sun to any one meridian on the earth (p. 664)
sorghum (sôr'gu̥m). A member of the grass family (p. 12)
sorrel (sŏr'e̥l). A plant with sour-tasting leaves (p. 159)
sounder, telegraph. An electromagnet with an armature placed above it, used for sending telegraph messages (p. 460)
species (spē'shēz). A distinct kind, or sort, of animal or plant (p. 35)
specific (spē sĭf'ĭk) **heat.** The number of calories required to raise the temperature of 1 gram of a substance 1° C. (p. 77)
spectroscope (spĕk'trō skōp). An instrument consisting of a prism, a narrow slit through which light may pass, and a lens (p. 703)
spectrum (spĕk'tru̥m) (*pl.* **spectra**). A band of color produced from white or other complex light by passing the light through a prism (p. 675)
sphygmomanometer (sfĭg mō ma̱ nŏm'ē tẽr). An instrument for measuring blood pressure (p. 552)
spiegeleisen (spē'ge̥l ī ze̥n). A mixture of metals added to the Bessemer converter during the process of manufacturing steel (p. 240)
spleen. A gland located in the lower part of the body cavity (p. 573)
spore. A living body which has the power to develop into a full-grown organism, as a plant (p. 166)
spurge (spûrj). A shrubby plant which has a milky bitter juice (p. 108)
standard-time system. A system of reckoning time by time zones which give average solar time (p. 667)
static (stăt'ĭk) **electricity.** A form of electricity in which electrons are stored on a nonconductor, as contrasted with current electricity, in which electrons flow along a conductor (p. 427)
steam chest. The part of a steam engine into which steam enters before going into the cylinder (p. 371)
steel. A tough alloy of iron with small quantities of carbon (p. 220)
stepped up. A term meaning the increase of voltage (and decrease of amperage) in an electric circuit (p. 493)
stethoscope (stĕth'ō skōp). An instrument which carries to the ear sounds produced in the body (p. 552)
stimulus (stĭm'ū lu̥s) (*pl.* **stimuli** (stĭm'ū lī)). Anything which stirs, or arouses, a receptor or the entire nervous system (p. 561)
stoma (*pl.* **stomata** (stō'ma̱ ta̱)). A very small opening, in the leaves of plants, through which gases, as oxygen and carbon dioxide, may move (p. 161)
stratosphere (strā'tō sfēr). That portion of the atmosphere more than seven miles above the earth's surface (p. 415)

streamline. To shape an object in such a way that it may pass easily through a fluid, as water or air (p. 317)

striated (strī'ā tĕd) **muscle.** Striped muscle (p. 543)

striations. Stripes (p. 544)

sturgeon (stûr'ju̱n). A large fish whose flesh is valued for food (p. 137)

submarginal (sŭb mär'jĭ na̱l) **land.** Land which is not quite fertile enough to provide a decent living for the farmer who attempts to cultivate it (p. 125)

substation. A number of step-down transformers grouped together (p. 499)

sucrose (sū'krōs). $C_{12}H_{22}O_{11}$, a sugar obtained from both the sugar cane and the sugar beet (p. 13)

sulfates. Salts formed from sulfuric acid (p. 76)

sulfur. S, a yellow solid, used for vulcanizing rubber. Sulfur compounds are widely used in industry (p. 84)

sulfuric acid. H_2SO_4, an oily, colorless liquid which can cause severe acid burns (p. 163)

supercharger. An instrument made for the purpose of compressing thin air and pumping it into the engine of an airplane at high elevations (p. 418)

symbol (sĭm'bu̱l). A letter or sign which represents a chemical element, as Fe is the symbol for iron (p. 251)

synapse (sĭ năps'). A junction between two neurons (p. 569)

tactile (tăk'tĭl). Having to do with the sense of touch (p. 561)

tapeworm. A parasite which lives in the intestine of man and various animals (p. 588)

taste buds. Sense organs on the tongue which contain the receptors for taste (p. 567)

technical (tĕk'nĭ ka̱l). Having to do with mechanical or scientific affairs (p. 419)

teletype (tĕl'ē tīp). A machine on which a message may be typed as on a typewriter. The striking of the keys causes a circuit to be closed and prints the message on paper fastened in the receiving machine (p. 461)

tellurium. Te, a nonmetallic element (p. 255)

tensile (tĕn'sĭl) **strength.** The force required to break by pulling apart a rod of material of one square inch in cross section (p. 270)

tent caterpillar. A kind of caterpillar. Groups infest trees and spin on the branches webs which resemble tents (p. 107)

teosinte (tē ō sĭn'tē). A native grass of Central America related to maize (corn) (p. 9)

terrace (*verb*). To plow and make ditches upon land in such a manner that erosion will not take place (p. 96)

terrarium (tĕ rā'rĭ u̱m). A habitat in which land animals may live and be studied (p. 119)

test tube. A small glass tube, closed at one end, in which chemical experiments may be carried out (p. 262)

thermal (thẽr'ma̱l). Having to do with heat (p. 359)

thermostat (thẽr'mō stăt). An automatic mechanism which regulates temperature (p. 616)

thyme (tīm). A shrub whose leaves are used for seasoning (p. 179)

thyroid gland. A large gland in front and on both sides of the windpipe (p. 585)

tidal theory. A theory which attempts to explain the formation of the earth (p. 711)

timer. A mechanism to supply electricity to the cylinders of a gasoline engine at the proper time (p. 393)

timothy. A form of grass used as hay (p. 105)

tin. Sn, a white metal, much used in alloys and as a protective plating for other metals (p. 201)

tin plate. Iron which has been plated with tin (p. 268)

tinstone. SnO_2, the ore from which tin is obtained (p. 209)

toxin. A poison produced by certain bacteria (p. 592)

transformer. An electrical instrument for changing the pressure (voltage) and quantity (amperage) of electricity flowing through a circuit. If the voltage is increased, it is known as a step-up transformer, and if the voltage is decreased, it is known as a step-down transformer (p. 493)

transmission gears. A system of gears in an automobile which carries power from the engine to the rear axle at various speeds (p. 400)

trichinosis (trĭk ĭ nō'sĭs). A disease of the intestines caused by a parasite (p. 632)

tuber. An underground stem (p. 18)

tundra (to͝on'dra̤). The treeless plain of the Arctic region (p. 80)

tungsten. W, a tough, steel-gray metal, used to make the filament in electric-light bulbs and to toughen steel (p. 215)

turbine (tẽr'bĭn). A machine in which the energy of running water or steam is used to develop electrical energy (p. 324)

ultra-violet rays. A form of radiant energy given off by the sun. These rays are invisible and help maintain health (p. 679)

uranium (ū rā'nĭ u̱m). U, a radioactive element (p. 711)

vacuum (văk'ū u̱m) **tube.** A tube emptied of air, in which movements of electrons may take place (p. 522)

valve. A mechanism in a pipe which closes or opens the passageway (p. 371)

vanadium (va̤ nā'dĭ u̱m). V, a rare, light-gray metal used as an alloy with steel (p. 215)

vegetative (vĕj'ē tā tĭv) **reproduction.** Certain plants can be formed from other plants without seeds. This reproduction is vegetative (p. 16)

vena cava (vē'na̤ kā'va̤). Either of the two veins which enter the right auricle of the heart (p. 550)

ventricle. One of the two lower chambers of the heart (p. 550)

vetch. A plant of the bean family, a legume (p. 88)

vitamin (vī'ta̤ mĭn). Any of a group of substances which exist in very

small quantities in different foods. They are necessary for proper nutrition (p. 540)

volt. A measure of the force (pressure) of the flow of electricity through a conductor (p. 488)

walking stick. An insect which eats leaves and resembles closely the twigs and branches on which it is found (p. 184)

water hemlock. A poisonous member of the carrot family (p. 160)

water hyacinth. A water plant of the lily family (p. 160)

watt (wŏt). A measure of electric power (p. 491)

wheat rust. A disease of the wheat plant, caused by a fungus (plant) (p. 165)

whelps. The young of certain animals, as dogs or tigers (p. 72)

whippet. A dog something like a greyhound (p. 58)

White Leghorn. A variety of chicken, noted for ability to lay eggs (p. 67)

white-pine blister. A fungus which lives upon and destroys the white pine (p. 165)

White Wyandotte (wī′ạn dŏt). A variety of chicken (p. 67)

Wood's metal. An alloy with a low melting point (p. 263)

wormwood. Ragweed. Wormwood has a bitter taste (p. 162)

X rays. A form of radiant energy with a short wave length. Such waves can penetrate certain substances, as flesh, thus making possible X-ray pictures (p. 539)

xenon (zĕn′ọn). X, a rare gaseous element found in the atmosphere (p. 255)

yarrow. A plant having small white flowers (p. 105)

yellow fever. A disease caused by an infection carried by a certain mosquito, the *Aëdes egypti* (p. 589)

zenith (zē′nĭth). The point in the heavens which is directly overhead, or above the observer (p. 659)

zinc. Zn, a bluish-white metal. Used in alloys and as a coating for sheet iron (p. 217)

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